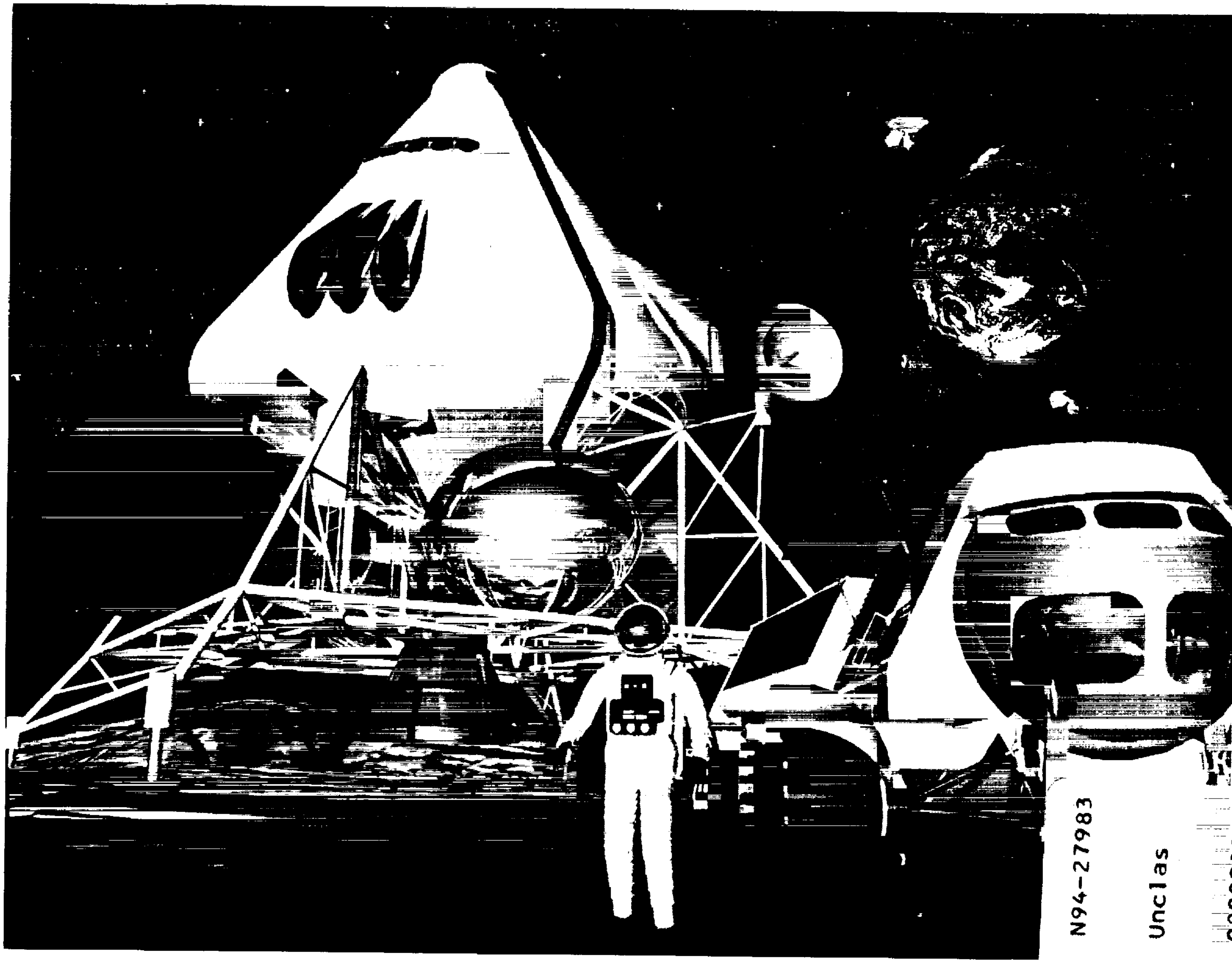

# Lunar Transportation Facilities and Operations Study – Option 2

## Annual Report
## February 1992


*McDonnell Douglas Space Systems Company*
*Kennedy Space Center*


**MCDONNELL DOUGLAS**

# Lunar Transportation Facilities and Operations
# Option 2
# Annual Report

prepared for

Office of Advanced Systems and Technology
NASA Kennedy Space Center

by

McDonnell Douglas Space Systems Company
Kennedy Space Center

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The Lunar Transportation Facilities and Operations Study team members (Art, J.Bob, Jeff, Ralph and Rex) would like to give special thanks to Jerry Flynn and Robert Humeniuk, McDonnell Douglas Visualization Group, for computerization and development of the cover.

# EXECUTIVE SUMMARY



## 1.0 Introduction

During the Option 2 period of the Lunar Transportation Facilities and Operations Study (LTFOS), a joint McDonnell Douglas Space Systems Company Kennedy Space Center (MDSSC-KSC) and National Aeronautics and Space Administration Kennedy Space Center (NASA-KSC) Study team conducted a comparison of the functional testing of the RL-10 and Space Shuttle Main Engine, a quick-look impact assessment of the Synthesis Group Report[1], and a detailed assessment of the Synthesis Group Report. This report contains the results of these KSC LTFOS team efforts.

The most recent study task effort was a detailed assessment of the Synthesis Group Report. The assessment was conducted to determine the impact on planetary launch and landing facilities and operations. The result of that effort is a report entitled "Analysis of the Synthesis Group Report, its Architectures and their Impacts on PSS Launch and Landing Operations" and is contained in Appendix A. The report is structured in a briefing format with facing pages as opposed to a narrative style.

A quick-look assessment of the Synthesis Group Report was conducted to determine the impact of implementing the recommendations of the Synthesis Group on KSC launch facilities and operations. The data was documented in a presentation format as requested by Kennedy Space Center Technology and Advanced Projects Office and is included in Appendix B.

Appendix C is a white paper on the comparison of the functional testing of the RL-10 and Space Shuttle Main Engine The comparison was undertaken to provide insight regarding common test requirements that would be applicable to Lunar and Mars Excursion Vehicles (LEV and MEV)

## 2.0 Analysis of the Synthesis Group Report

Four architectures were identified by the Synthesis Group that differ significantly in the degree of human presence, exploration, science, and space resource development for the benefit of Earth. They are:

- I Mars Exploration
- II Science Emphasis for the Moon and Mars
- III The Moon to Stay and Mars Exploration
- IV Space Resource Utilization

To identify the impacts to planetary launch and landing operations each architecture was reviewed in-depth. Recommendations to minimize these impacts were then identified.

The Synthesis Group Report did not describe in any detail the vehicles that would be landing and/or launched from the lunar and Martian surfaces. Therefore, assumptions were required regarding vehicle design and configuration. Two configurations were considered for the Lunar Excursion Vehicle (LEV) and Mars Excursion Vehicle (MEV), cargo landers, that are expended on the planetary surface, and piloted vehicles. Two designs considered for the piloted vehicles were:

1. Two stage vehicles, similar those used on Apollo missions, using storable propellants with expendable descent and expendable ascent stages.

2. Single stage, reusable, vehicles for descent and ascent using cryogenic

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[1]Synthesis Group report "America at the Threshold, America's Space Exploration Initiative", dated May 3 1991.

propellant similar to the type described in the Ninety (90) Day Report, Option 5a[2]. Some of the parameters that would impact launch and landing operations are specified in the Synthesis Group Report, while others are inferred, but not specified. The parameters used as ground rules in the assessment of the Synthesis Group Report are listed below:

- Crew size
- Surface stay times
- Launch and landing rates
- Facilities and services
- Number of planetary bases and sites
- Surface support equipment
- Number of launch and landing pads

The crew size, the length of time spent on the planetary surface and the number of missions are specified in the Synthesis Group Report.

For Architectures I, II, and IV the number of lunar crew members on the surface at one time would never exceed six (the six Mars dress rehearsal crew members were not considered part of the lunar crew, because they would not participate in the lunar operations). For Architecture III a permanent base would be established. The lunar crew size would start with a six member crew serving a 365 day tour of duty. Additional crews would arrive at the base for 365 day tours such that the crew size would build up to an 18 member crew (excluding the six Mars dress rehearsal crew members). For Mars missions crew size would never exceed six.

During normal piloted lunar missions the time that the crew would stay on the surface steadily increases from 14 days during the initial missions for all architectures to 365 days during the operational phase of Architecture III. During the Mars dress rehearsal mission, conducted on the lunar surface, the crew would remain on the surface up to 40 days. During Mars piloted missions, crews would stay on the Martian surface for 30, 100 or 600 days.

The maximum number of launches and landings was determined by the number of missions specified in the Synthesis Group Report for each architecture. The maximum number of landings and/or launches for any of the architectures occurs during the Mars dress rehearsal missions.

Facilities and services provided specifically for launch and landing operations are not identified in the Synthesis Group Report. However, facilities and services would be required for any sustained launch and landing operation from the surfaces of the Moon and Mars. Required facilities would include:

- Launch and landing pads
- Habitat for crew members
- Pressurized work area with workbench for minor repairs and hand tools

Each architecture in the Synthesis Group Report is described in terms of operational capability, starting with an initial operational capability and continuing through several levels of capability. There is no specific mention of bases or sites, but it is implied that there would be both fixed bases and simple landing sites. For example, during the early phase of Architecture II landing sites at three potential base locations would be surveyed on the first three missions and one of these sites would be selected as the location for a permanent base. During the analysis the number of bases and sites was determined from a review of each operational capability for each architecture.

Services required specifically for launch and landing operations would include:

[2]Reference Architecture Description, Option 5a, (Option 5 with ISRU Emphasis), PSS Reference Architecture Document 90-2, May 22 - 24, 1990.

- Transportation service from the launch site to and from the habitat for surface crews during launch and landing operations
- Electrical power for LEVs and MEVs during long duration stays to conserve flight fuel cells or batteries
- Construction services to remove obstacles from launch and landing pads

Surface support equipment provided specifically for launch and landing operations is not identified in the Synthesis Group Report. However, surface support equipment would be required for any sustained launch and landing operations from the surfaces of the Moon and Mars. Based on the Architectures described in the 90-Day Report and a baseline cryogenic, reusable LEV surface support equipment for launch and landing operations was recommended to MASE during the trade studies in 1990. The equipment recommended during MASE included:

1. LEV and MEV Servicer with the following subsystems:
   - Cryogenic Propellant Management
   - Thermal Control
   - Electrical Power
   - Data management, Command and Control System
2. Thermal/Micrometeoroid Protection
3. Waste Management Service System
4. ECLSS Service System
5. Fuel Cell Service System
6. Lunar LOX Pallet
7. Auxiliary Lighting Equipment
8. Navigation Aids
9. Access Equipment
10. Engine Blast Protection
11. Data management and Communication System (Habitat)
12. Command and Control Telemetry Link (Earth to planetary surface)

The equipment considered applicable to the various operational phases of each architecture was identified.

Pad quantities are strongly influenced by excursion vehicle design. The type of vehicles considered in the analysis included single stage LEVs and MEVs, as well two stage vehicles, and the number of pads and sites that were identified for each vehicle type considered, and each architecture.

Launch and landing scenarios for Option 5a were developed for the Planetary Surface Support Office (PSS) at Johnson Space Center as support for the 90 Day study[3]. Each operation within a scenario was supported by detailed functional task flows. Launch and landing scenarios for the early lunar missions of Architectures I thru IV would be essentially the same as early Option 5a manned missions. Launch and landing scenarios for Architectures I, II and IV long duration lunar missions would be the same as the Option 5a manned operational missions. Scenarios for Architecture III operational lunar missions with the permanently manned lunar base would be similar to the original baseline scenario developed during the initial phase of LTFOS[4]

It was concluded that there would be no need for a large infrastructure for the lunar missions of Architectures I, II and IV. Minimal facilities, services and surface support equipment would be required for these missions, because there are only a few missions of relatively short duration. One pad for piloted launches and landings with minimal navigation aids should be sufficient. However, thermal and micrometeoroid protection would be required, as well as an LEV Servicer (i. e., thermal conditioning system for storable

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[3]Based on Reference Architecture Description, Option 5a (Option 5 with ISRU Emphasis), PSS Document 90-2, May 1990.

[4]Lunar Transportation, Facilities and Operations Study, Final Report, April 1990.

propellants, or propellant management system for cryogenic propellants).

It is recommended that the LEV onboard computers and BIT/BITE for LEV and Servicer checkout be used for test, checkout and monitoring of the performance of the LEV and Servicer. Also, it is recommended that the standard mission communications links be used to meet all launch and landing operations, earth-to-LEV, LEV-to-base and base to earth communication requirements. Other standard mission equipment should be used for crew surface transport and cargo surface handling and transport.

The launch and landing scenarios for Architectures I, II and IV would be essentially the same as those developed for Option 5a of the 90 Day Study.

A large launch and landing infrastructure would be required for the lunar missions of Architecture III because under this architecture, the base would become a permanent launch and landing complex receiving cargo and replacement crews on a regularly scheduled basis. This would require dedicated facilities, services and a full compliment of surface support equipment. A minimum of four pads for piloted launches and landings would be required.

Further studies and experiments should be conducted to develop a better understanding of ejecta effects, and to develop protection techniques for protecting LEVs on the surface from ejecta produced by arriving cargo landers, and arriving and departing piloted vehicles.

## 3.0 Quick-look Assessment of the KSC Impacts of the Synthesis Group Report

When the Synthesis Group Report was first published the NASA MDSSC KSC LTFOS Study team was requested to conduct a quick-look assessment of the impacts the recommendations of the report would have on KSC launch facilities and operations. The report calls for, and discusses a heavy lift launch vehicle (HLLV), but does not discuss the role of the Space Shuttle. It was assumed that throughout the Space Exploration Initiative (SEI) time period, the Shuttle, or its replacement, will continue to launch the typical class of payloads it has these past ten years and to resupply Space Station Freedom. The launch rate will fully utilize the existing boosters and payload facilities.

GENERAL OBSERVATIONS:

The SEI missions, as defined in the Synthesis Group Report, will require new launch pads and payload processing facilities to accommodate payloads up to 250 metric tons. High technology payloads will require unique support.

The method KSC uses to process the Shuttle and payloads will have to be evaluated, and where appropriate, new ground operational techniques developed to handle the increase of processing flows more efficiently and effectively i.e., scheduling techniques, process automation, etc.

IMPACTS:

A separate KSC SEI Program Office (similar to the Space Station Office) would be required.

All of the SEI architectures utilize lunar and Martian transfer vehicles, landers, and extraterrestrial elements such as habitats. Previous studies assessed existing and currently planned KSC payload facilities for suitability and availability to support SEI launch rate[5]. A minimum of four new payload processing facilities were identified, including a large payload integration facility and facilities for processing of individual SEI elements. It appears that

[5]MSFC Launch/On-Orbit Processing Study, 1989

the schedules shown for each of the architectures will include only operational flights. Additional flights will be required to support research and developments efforts which will add to the amount of payload processing that will be required at KSC, be it either on the Shuttle or on other vehicles. For example, the SEI program will probably require a flight assessment of the nuclear propulsion system which will add to the amount of payload processing resources required at KSC to support the program.
The schedules also do not indicate the processing and the launching of Mars synchronous relay satellites. However, the report indicates that there is a relay satellite network. It is highly probable that such a communication system will be used and these satellites will be processed and launched as payloads.

The initial architectures discuss the requirements for precursor flights as early as 1998 to 2005. The time between these flights and the landing of men and/or cargo can be as long as 14 years. (Reference Architecture I). It is probable that other precursor flights will be needed in the intervening years. The schedule does not reflect that additional data gathering flights might make a greater impact on the payload processing capability than is being considered at this time.

Ka Band communications are baselined for all Mars architectures. KSC capabilities to process Ka Band data and relay it to other sites (JSC, JPL) in support of payload test and checkouts will be required.

Architecture IV envisions the downloading to Earth of two metric tons of Helium-3 annually. This may require capabilities which are beyond the normal KSC payload offloading and safing capabilities already in existence.

Lunar and Mars missions will result in equipment, vehicles, and facilities, being carried to and left on extraterrestrial surfaces with the intent of returning to and reusing them during long term surface operations. An integrated logistics support system and infrastructure capable of tracking planetary surface and space vehicle support requirements will be required to retain these systems in and operational state.

Nuclear power has been baselined for all Mars surface power and nuclear thermal rocket propulsion Mars transfer vehicles. Current KSC RTG facilities are insufficient for processing and storing the Mars nuclear reactor payloads. A new KSC nuclear reactor processing facility is required.

The large amounts of propellants which are to be used will require either large storage and tanking areas or local production. If other program launches are to continue, enough propellant may be required to justify local production. This should become the subject of an assessment to determine anticipated requirements.

Robotics and telepresence are mentioned in numerous places in the document. There must be a capability to test and checkout the equipment.

An increased reliance on life support systems (especially if the system is to be closed) will place a greater emphasis on KSC CELSS projects. KSC is a leader in closed chamber plant studies and is the NASA lead center for plant space biology.

Other considerations should be given to the preparations for closed loop systems. If humans, and associated biological systems are to be sent on a long duration flight, extended quarantine periods will be required. The magnitude of supporting this quarantine will require additional KSC involvement.

The payloads will be comprised of several different launch elements, and require a wide range of technologies and support requirements. The varying nature of the payloads makes them more complicated than the repetitive launch vehicle preparations. Therefore, a far more diverse set of support requirements and unique state-of-the-art technical needs must be addressed for the payload processing activities than considered in the past and for launch vehicles.

## 4.0 Comparison of the RL10 and SSME Functional Testing

One element common to all of the Lunar Excursion Vehicle or Mars Excursion Vehicle (LEV and MEV) concepts developed to date during the Space Exploration Initiative (SEI) transportation studies was the use of multiple cryogenic propellant (LOX/LH2) engines, with a combined thrust level in the range of 60,000 to 80,000 pounds. Advanced models of the RL10 type were the engines of choice. The primary purpose of this study was to emphasize the fact that a great deal of prelaunch activity, related to space vehicle testing and particularly engine checks, is currently accomplished on this planet at the launch site prior to the launch countdown.

The RL10 Liquid Rocket Engine has been operational since 1962 and is currently used on the Centaur vehicle. Centaur prelaunch testing is complex. One hundred and four tests are performed on Centaur alone. Many of these tests are related to the RL10 engines. In addition, functional tests are performed on the engine at the manufacturer's plant, prior to installation in the Centaur and again at the launch site. These tests require the use of special purpose ground support equipment, a team of engineers, and skilled technicians. All tests are considered necessary to assure successful launch from this planet and it would be reasonable to assume that some similar type of testing would be required for the LEV and MEV prior to descent from low lunar orbit, or low Martian orbit, and prior to lift-off from another planetary surface.

The purpose of performing LEV and MEV preflight checks is to provide confidence that the vehicle systems and subsystems will function properly, and to detect malfunctions that would present a safety hazard. For the reusable vehicles the data obtained over a series of tests could be assessed for trends that may signal an impending failure. Due to the limited resources available to conduct preflight checks in space or on a planetary surface, the LEV and MEV would require a high degree of automation, with embedded sensors, to provide a built-in-test/built-in-test-equipment (BIT/BITE) capability. The current RL10 engine design has essentially no built-in-test capability.

The Space Shuttle Main Engine (SSME) is the only other operational rocket engine currently in the NASA inventory which uses LOX/LH2 as the propellant. The SSME is an advanced design engine with a limited built-in-test capability. Although the RL10 and the SSME are based on completely different designs, comparing the functional tests performed on these engines provided insight regarding common test requirements that would be applicable to the LEV and MEV.

Planetary resources for LEV and MEV functional test would be extremely limited. Crew size for example would be limited to four crew members under the SEI 90-Day Study architectures, and six crew members under the plan proposed in the Syntheses Group Report. Support equipment would also be limited. The LEV and MEV Servicer may be available on a planetary surface; however, external support equipment would not be available in low lunar orbit for preflight checks prior to descent burn.

Performing engine functional tests using techniques currently employed for the RL10 would be totally impractical. The LEV and MEV engines would require a high degree of self test capability. The best way to measure performance and check functionality is to fire the engine. On the Orbiter for example the SSMEs are started and performance verified prior to igniting the solid rocket boosters (SRBs). If any of the SSMEs fail to start or the performance is marginal the SRBs are not ignited, the SSMEs are shut down and the launch is aborted.

This would be the recommended approach for launches from a planetary surface provided the LEV and MEV engines can be started in a throttled down condition (e. g., 20% of rated thrust) such that there is no tendency to lift-off. However, firing the LEV and MEV engines to measure performance, prior to descent from orbit may not be practical, because any thrust produced by the engines would affect the vehicle's orbit.[6]

One of the major design improvements required for advanced models of the RL10 for on-orbit or planetary preflight functional verifications would be the incorporation of embedded sensors and computer controlled test programs to provide a BIT/BITE capability.

Recommended checks that should be considered for the preflight functional test are discussed in the white paper (see Appendix C) and include:

1. Electrical system tests, including ignition system verification
2. Turbine torque checks
3. Valve actuation checks
4. Combined internal/external fuel system leak checks (pressure decay checks)

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6 Until an analysis is performed to determine whether the impact could be nullified in some manner, this would not be considered a viable option for the pre-descent engine checkout.

# Appendix A

## Report on the

## Analysis of the Synthesis Group Report,

## its

## Architectures and their Impacts

## on PSS Launch and Landing Operations

# Appendix A

This appendix contains the results of the joint NASA and MDSSC KSC LTFOS team detailed analysis of the Synthesis Group Report. The report is structured in a briefing format as opposed to a narrative style for presentation to the Planetary Surface Systems Office.

# Report on the
# Analysis of the Synthesis Group Report,
# its
# Architectures and their Impacts
# on PSS Launch and Landing Operations

Revision A

24 January 1992

prepared for

Office of Advanced Systems And Technology

NASA Kennedy Space Center

by

McDonnell Douglas Space Systems Company

Kennedy Space Center

NASA Contract Number: NAS10-11567

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

Vice President Quayle requested NASA "to find the most innovative ideas in the country" to meet the challenge of the Space Exploration Initiative Program. These ideas were solicited by NASA Administrator, Richard H. Truly, through an Outreach Program of personal letters and public announcements.

Lieutenant General Thomas P. Stafford, USAF (Ret.), was asked by Vice President Quayle and Administrator Truly to serve as chairman of a group to analyze and synthesize the recommendations of the Outreach Program. Twenty-three senior members, all professionals with vast experience and of national regard, participated in working sessions to direct the Synthesis Group's efforts.

"America at the Threshold, Report of the Synthesis on America's Space Exploration Initiative" was published on 3 May 1991. Four architectures were identified, differing significantly in the degree of human presence, exploration, science, and space resource development for the benefit of Earth. They are:

- I Mars Exploration
- II Science Emphasis for the Moon and Mars
- III The Moon to Stay and Mars Exploration
- IV Space Resource Utilization

The Planetary Surface Support Group at NASA JSC requested the NASA KSC and MDSSC KSC Lunar Transportation, Facilities and Operation Study team to analyze these architectures, and determine their impacts on planetary launch and landing operations. This report is a result of that effort.

The agenda will first address the purpose and approach used in the analysis. This will be followed by assumptions that were made, ground rules used, results, conclusions and recommendations.

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

## Agenda

➡ - Purpose and Approach

- Assumptions

- Ground Rules

- Results

- Conclusions and Recommendations

## Purpose and Approach

An in-depth review of each architecture was conducted of those parameters that would impact launch and landing operations. The impacts were then assessed and recommendations made with respect to enhancing launch and landing operations.

# Purpose and Approach

- ❑ Analyze each of the architectures described in the Synthesis Group Report* and determine:

  - Surface stay times
  - Crew size
  - Number of planetary bases and sites
  - Number of L&L pads
  - Launch and landing rates
  - Facilities and services
  - Surface support equipment

- ❑ Evaluate impacts to launch and landing operations with respect to:

  - Launch and landing scenarios
  - Additional facilities and services required
  - Additional surface support equipment required
  - Thermal consideration for vehicles using storable propellants

- ❑ Provide recommendations to enhance launch and landing operations for consideration by:

  - Mission planners
  - LEV and MEV designers
  - Surface support equipment designers

* Synthesis Group report "America at the Threshold, America's Space Exploration Initiative", dated May 3 1991

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

**Assumptions made in performing the impact assessment are discussed in this section.**

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

## Agenda

- Purpose and Approach
- ➡ Assumptions
- Ground Rules
- Results
- Conclusions and Recommendations

## Assumptions

The Synthesis Group Report did not describe in any detail the piloted vehicles that would be landing and launched from the lunar and Martian surfaces. However, the report does state that on initial piloted missions to the Moon, five crew members will descend to the surface, while one will remain in orbit to perform experiments, and to monitor the orbiting vehicle. On Mars missions all six crew members would descend to the surface, because the reliability of the orbiting vehicle will have been verified during the lunar missions. This approach, similar to that used during the Apollo program, would suggest that the vehicles are similar to the Apollo command modules and excursion vehicles. In this report, the excursion vehicles are referred to as the Lunar Excursion Vehicle (LEV) and the Mars Excursion Vehicle (MEV).

Also, the Synthesis Group Report states that an all-chemical propulsion system will be used for the lunar missions similar to the Apollo program. In the description of Architecture IV, the initial propulsion for lunar ascent/descent vehicles (LEVs) is conventional chemical, employing liquid hydrogen or methane as fuel. One of the basic features of Architecture IV is the development of reusable landing vehicles, that will be refueled on the lunar surface with lunar-derived hydrogen, or methane and lunar-derived oxygen.

The following charts describe the LEV and MEV configurations and designs considered in this analysis.

# Assumptions
# LEV and MEV Configurations and Designs

- Two (2) LEV and MEV configurations
  - Piloted vehicles and cargo landers (all cargo landers are expended on the planetary surface)
- Two (2) LEV and MEV designs considered for Synthesis Group Architectures
  - Two stage vehicles similar to Apollo missions using storable propellants, expendable descent stage and expendable ascent stage for early missions
  - Ninety (90) Day Report, Option 5a* type vehicles using cryogenic propellant reusable single stage descent/ascent vehicles for later missions

Note: The Synthesis Group Report states that storable propellant vehicles are baselined for low thrust lunar ascent/descent missions. Vehicles using cryogenic propellants need to be developed and demonstrate long term storability. Once validated, cryogenic vehicles could be phased-in for later lunar and Mars missions. The report does not discuss split ascent/descent stage lunar vehicles.

* Reference Architecture Description, Option 5a, (Option 5 with ISRU Emphasis), PSS Reference Architecture Document 90-2, May 22 - 24, 1990

## Assumptions (Continued)
## LEV and MEV Configurations and Designs

**Page A-10 describes the LEV designs considered in this analysis.**

# Assumptions (Continued)
# LEV and MEV Configurations and Designs

- LEV Designs
  - Designed with a combination tank size and tank insulation material that:
    - Permit LEVs using storable propellants to remain on the surface for 14 days during the lunar daylight without excessive propellant boiloff
    - Permit LEVs using cryogenic propellants to remain on the surface for 30 days without excessive propellant boiloff
  - Designed to interface with an external active thermal conditioning system (cooling and/or heating), or contain a built-in system, to reduce propellant boiloff during the lunar day and prevent propellant from freezing during the lunar night for:
    - LEVs using storable propellants that remain on the surface for long durations
  - Designed to interface with an external active propellant management system (reliquefaction and/or refrigeration), or contain a built-in system, to reduce propellant boiloff for:
    - LEVs using cryogenic propellants that remain on the surface for durations greater than 30 days

## Assumptions (Continued)
## LEV and MEV Configurations and Designs

**Page A-12 describes the MEV designs considered in this analysis.**

# Assumptions (Continued)
# LEV and MEV Configurations and Designs

- MEV Designs
  - Designed to interface with an external active thermal conditioning system (heating), or contain a built-in system, to prevent propellant from freezing for:
    - MEVs using storable propellants
  - Designed to interface with an external active propellant management system (reliquefaction and/or refrigeration), or contain a built-in system, to prevent excessive propellant boiloff for:
    - MEVs using cryogenic propellants
- With respect to electrical power and thermal control, MEVs are self-sufficient for short duration surface stay times (up to 30 days) at either landing sites or bases

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

This section discusses the ground rules established for performing the impact assessment. These ground rules are actually a set of parameters, that when combined with the assumptions, define the scope of the assessment.

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

## Agenda

- Purpose and Approach
- Assumptions
- ➡ Ground Rules
- Results
- Conclusions and Recommendations

# Ground Rules

Areas that would impact launch and landing operations are shown on page A-16.

Some of these parameters are specified in the Synthesis Group Report, while others are inferred, but not specified. The parameters used as ground rules are listed in the following pages, and discussed in detail under the Results Section in this report.

# Ground Rules
# Parameters Impacting L&L Operations

- Areas that would impact launch and landing operations include:
  - Surface stay times
  - Crew size
  - Number of planetary bases and sites
  - Number of L&L pads
  - Launch and landing rates
  - Facilities and services
  - Surface support equipment

- Parameters specifically called out in the report* are planetary stay times and crew sizes as shown on page A-18
  - Stay times and crew size are considered baseline ground rules in determining launch and landing operations

- Other parameters inferred in the report*, but not specified, are discussed under results and include :
  - The number of bases and sites
  - The number of L&L pads
  - Launch and Landing rates
  - Facilities and Services
  - Surface Support Equipment

* Synthesis Group report "America at the Threshold, America's Space Exploration Initiative", dated May 3 1991

## Surface Stay Times and Crew Size

Page A-18 shows the crew size and surface stay times that are specified in the Synthesis Group Report.

# Surface Stay Times and Crew Size

- Planetary stay times steadily increase
  - Normal lunar piloted missions 14; 45; 90; 180; 365 days
  - Mars dress rehearsal piloted mission 30; 40 days
  - Mars piloted missions 30 - 100; 600 days
- Lunar Crew size
  - For Architectures I, II, and IV the number of lunar crew members on the surface at one time never exceeds six (the six Mars dress rehearsal crew members are not considered part of the lunar crew, because they will not participate in the lunar operations)
  - For Architecture III lunar crew size builds up to a permanent 18 member crew (excluding the six Mars dress rehearsal crew members)
- Mars crew size never exceeds six

## Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

**This section describes the results of the analysis effort.**

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

## Agenda

- Purpose and Approach
- Assumptions
- Ground Rules
- ➡ Results
- Conclusions and Recommendations

## Analysis of the Synthesis Group Report Architectures
## Results

The results of the assessment are described in terms of those parameters that would impact launch and landing operations.

The first parameter described is the number of bases and sites.

# Analysis of the Synthesis Group Report Architectures Results

❑ The following charts describe the results of the evaluation with respect to:

➡ - Number of planetary bases and sites

- Number of L&L pads

- Launch and landing rates

- Facilities and services

- Thermal considerations for storable propellants

- Surface support equipment

- L&L operational scenarios

## Number of Planetary Bases and Sites
## Architectures I and II

Each architecture in the Synthesis Group Report is described in terms of operational capability, starting with an initial operational capability and continuing through several levels of capability. There is no specific mention of bases or sites, but it is implied that under certain operational capabilities there will be fixed bases from which astronauts will operate, while in others the only operations consist of landing to make a survey of the area and then returning to earth. The number of bases and sites described in the following charts were determined from a review of each operational capability for each architecture.

# Number of Planetary Bases and Sites*
# Architectures I and II

- Architecture I

  - One lunar base for four piloted missions
  - One base near the lunar base for the Mars dress rehearsal mission (Two optional missions may be sent to the Mars dress rehearsal base for Mars equipment redesign testing if required)
  - Two different Mars bases for two piloted missions (Destination for two optional missions is unknown)

- Architecture II

  - Three lunar landing sites for the first three piloted missions
  - One lunar base for the next three piloted missions (selected from one of the landing sites)
  - One base near the lunar base for the Mars dress rehearsal mission
  - Possibly four different lunar sites for the last four piloted missions
  - Up to four different Mars bases for four piloted missions (Last base becomes permanent Mars base)



* See chart on page A-28

## Number of Planetary Bases and Sites (Continued)
## Architectures III and IV

Page A-26 describes the number of bases and sites for Architectures III and IV.

# Number of Planetary Bases and Sites (Continued) Architectures III and IV

- ❑ Architecture III

  - One lunar base for all piloted missions
  - One base near the lunar base for the Mars dress rehearsal mission

  - Two different Mars bases for two piloted missions (Destination for two optional missions is unknown)

- ❑ Architecture IV*

  - One lunar site for the first piloted mission
  - One lunar base for the next four piloted missions (Destination for three optional missions is unknown)

  - One base near the lunar base for the Mars dress rehearsal mission
  - One Mars base for two piloted missions (Destination for one optional mission is unknown)

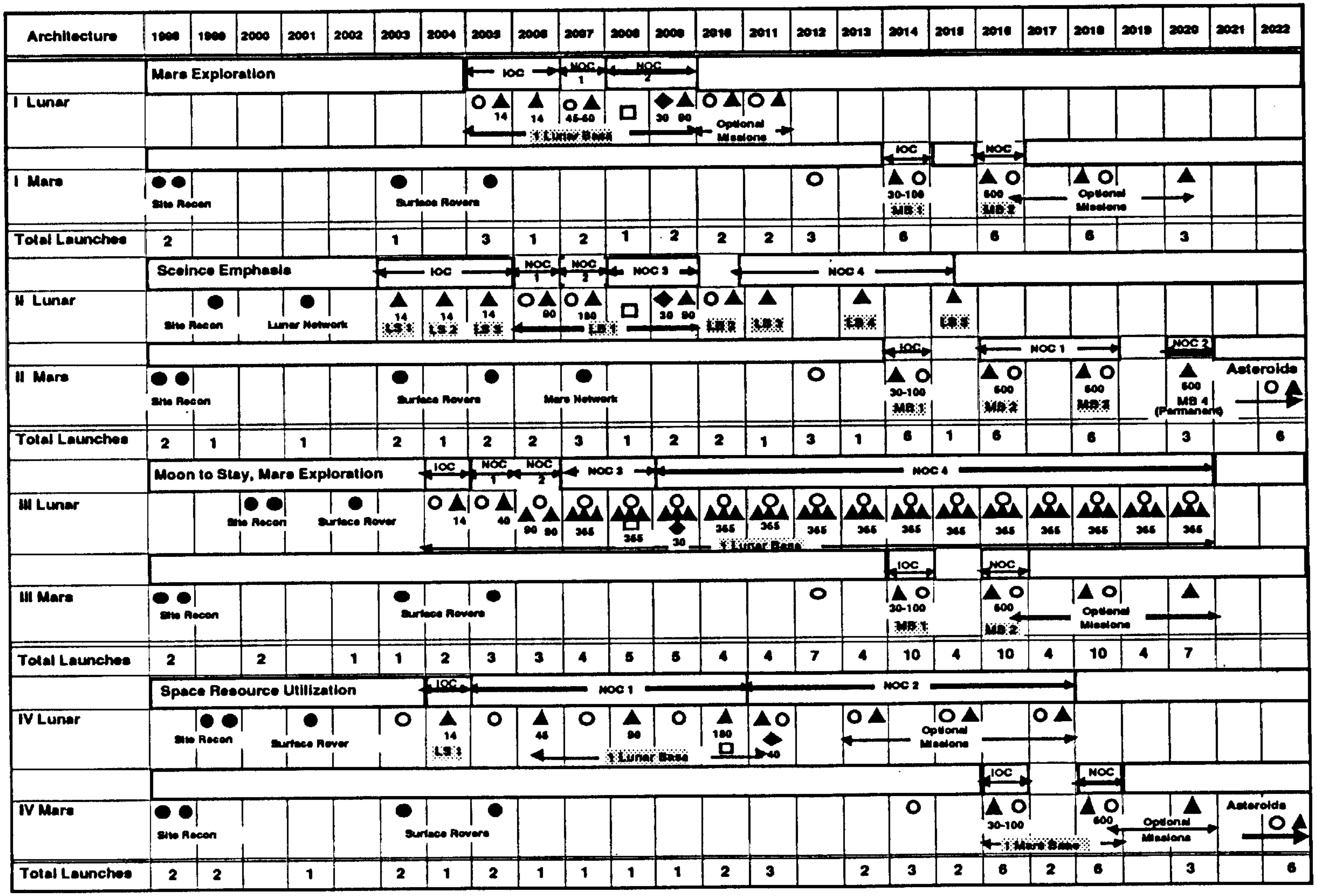
* It is assumed that the cargo mission in 2011 is intended to support the Mars dress rehearsal observation crew that arrives on the lunar piloted mission in 2011, and that this mission is mislabeled in the Synthesis Report as an optional mission. This assumption is based on the fact that all other piloted missions in Architecture IV are supported by cargo missions, either one year prior to the piloted mission, or during the same year as the piloted mission.

## Number of Planetary Bases and Sites (Continued)
## Summary

**This chart summarizes the number of bases and sites for all architectures. The chart also shows the relationship between the bases and sites, the operational capability, and the overall schedule.**

# L&L Pads for Architecture I thru IV Summary

Updated 10 Sept 1991




**Note:**

All Mars cargo and piloted missions and asteroids cargo and piloted missions require 3 earth-to-LEO HLLV (250 - 300 tonne) launches.

**Legend:**

- ● Mission Precursor
- ○ Cargo Mission
- ▲ Piloted Mission
- □ Mars Dress Rehearsal (Cargo)
- ◆ Mars Dress Rehearsal (Piloted. Located nearby lunar base)

LS = Landing Site
LB = Lunar Base
MB = Mars Base

## Analysis of the Synthesis Group Report Architectures
## Results

**The number of launch and landing pads is the next parameter described.**

# Analysis of the Synthesis Group Report Architectures Results

- ❑ The following charts describe the results of the evaluation with respect to:
  - Number of planetary bases and sites
  - ➡ Number of L&L pads
  - Launch and landing rates
  - Facilities and services
  - Surface support equipment
  - Thermal considerations for storable propellants
  - L&L operational scenarios

## L&L Pads
## Architectures I thru IV

Pad quantities are strongly influenced by excursion vehicle design. The type of vehicles considered in the report included single stage LEVs and MEVs, as well two stage vehicles.

For single stage LEVs and MEVs, where the ascent and descent functions will be combined in one vehicle, a single pad will be sufficient (assuming minimal or no pad damage at launch). However, multiple pads are recommended for permanent bases with high launch and landing rates (i. e., Architecture III).

With two stage LEVs and MEVs, where the ascent and descent functions will be performed by separate stages, the descent stage will be expended on the planetary surface (Apollo approach).

# L&L Pads
# Architectures I thru IV

- Pad quantities are strongly influenced by excursion vehicle design
  - Single stage LEVs and MEVs
    - Ascent and Descent functions combined in one vehicle
  - Two stage LEVs and MEVs
    - Ascent and Descent functions performed by separate stages
    - Descent stage is expended on planetary surface (Apollo approach)

- Single stage vehicle impact is modest
  - A Single pad is sufficient in most cases (assumes no pad damage at launch)
  - Multiple pads are recommended for permanent bases

## L&L Pads
## Architectures I thru IV (Continued)

The number of launch and landing pads required for two stage LEVs and MEVs, where the ascent and descent functions performed by separate stages, will be dependent on the size and mass of the descent stage, and/or the capability of lifting and moving equipment on the planetary surface.

Several assumptions were made with regard to cargo landers.

# L&L Pads
## Architectures I thru IV (Continued)

- ❑ Impact of two stage vehicles on number of pads dependent on size and weight of descent stage
  - If size and weight exceeds capacity of lifting and moving surface support equipment:
    - - -Vehicle must be abandoned in place
    - - -Number of pads will be determined by the number of flights
  - If size and weight allows removal to storage area
    - - -Number of pads identical to single stage vehicles
- ❑ All cargo landers:
  - Are landed at sites that are accessible for cargo removal by telerobotic unloader/mover or crew
  - Are landed at sites without causing ejecta damage to base equipment and facilities
  - Are landed at sites that will not interfere with future landing operations for piloted missions
  - Are a potential source of spare parts if design is common to piloted vehicles

## L&L Pads
## Architectures I thru IV (Continued)

Architecture III with its ambitious number of missions (i. e., 17 Cargo flights and 46 Piloted flights) will impose the greatest impact on the number of launch and landing pads at the lunar base.

# L&L Pads
# Architectures I thru IV (Continued)

- Architecture III imposes the greatest impact on the lunar base
  - Ambitious number of missions
    - 17 Cargo flights
    - 46 Piloted flights
  - Doubt exists that 17 cargo landing sites can be located conveniently near base
    - Recommend expended cargo landers be moved to storage area if possible
  - With two stage piloted vehicles where size and weight preclude removal
    - 46 Landing sites would be required
  - With two stage piloted vehicles where size and weight permit removal
    - Storage area required for 46 piloted vehicle descent stages
  - Even if cargo landers and descent stages can be moved from landing area, storage becomes a problem
    - Storage area required for a total of 63 vehicles

## L&L Pads
## Architectures I thru IV Summary

The chart on page A-38 summarizes the number of launch and landing pads for all architectures. This chart also illustrates the relationship between the number of pads and operational capabilities.

# L&L Pads
# Architectures I thru IV Summary

| Launch & Landing Pads & Sites | Architecture I | | | | Architecture II | | | | | | | | | | | Architecture III | | | | Architecture IV | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base | LB 1 | MDR NBLB | MB 1 | MB 2 | LS 1-3 | LB 1 | LB 2 | LB 3 | LB 4 | LB 5 | MDR NBLB | MB 1 | MB 2 | MB 3 | MB 4 Perm | LB 1 | MDR NBLB | MB 1 | MB 2 | LS 1 | LB 1 | MDR NBLB | MB 1 |
| Operational Phase | IOC NOC 1 & on | | IOC | NOC | IOC | NOC 1-3 | NOC 4 | NOC 4 | NOC 4 | NOC 4 | | IOC | NOC 1 | NOC 1 | NOC 2 | IOC NOC 1-4 | | IOC | NOC | IOC | NOC 1 & 2 | | IOC NOC |
| Missions | | | | | | | | | | | | | | | | | | | | | | | |
| Cargo Flights | 2 | 1 | 1 | 1 | | 2 | 1 | | | | 1 | 1 | 1 | 1 | 1 | 17 | 1 | 1 | 1 | 1 | 4 | 1 | 2 |
| Piloted Flights | 4 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 46 | 1 | 1 | 1 | 1 | 4 | 1 | 2 |
| Optional Missions | | | | | | | | | | | | | | | | | | | | | | | |
| Cargo Flights | | 2* | | 2 | | | | | | | | | | | | | | | 2 | | 3 | | 1 |
| Piloted Flights | | 2* | | 2 | | | | | | | | | | | | | | | 2 | | 3 | | 1 |
| Number of Landing Sites** | | | | | | | | | | | | | | | | | | | | | | | |
| Cargo | 2 | 1(3)* | 1 | 1 (3) | | 2 | 1 | | | | 1 | 1 | 1 | 1 | 1 | 17 | 1 | 1 | 1 (3) | 1 | 4 (7) | 1 | 2 (3) |
| Piloted (Two Stage) LEV/MEV | 4 | 1(3)* | 1 | 1 (3) | 1 ea LS | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Mission Dependent | 46 | 1 | 1 | 1 (3) | 1 | 4 (7) | | 2 (3) |
| Number of L&L Pads*** | | | | | | | | | | | | | | | | | | | | | | | |
| Piloted (Single Stage) LEV/MEV | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 4 min | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

IOC = Initial Operational Capability
LB = Lunar Base
MB = Mars Base

MDR = Mars Dress Rehearsal
NBLB = Near By Lunar Base
NOC = Next Operational Capiblity

Landing Sites = Unprepared suface areas.
L&L Pad = Prepared landing surface which can support launches.
( ) = Total number of sites required if optional missions are flown.

Notes: * Optional missions for Mars equipment redesign testing if required, would go to MDR NBLB.
** Assumes that Cargo Landers and descent stage of two stage LEVs cannot be moved from landing area.
*** Assumes that L&L Pads can be prepared telerobotically for any lunar piloted mission that is preceded by a Cargo Lander.

## Analysis of the Synthesis Group Report Architectures
## Results

**Launch and landing rates are discussed next.**

# Analysis of the Synthesis Group Report Architectures Results

❑ The following charts describe the results of the evaluation with respect to:

- Number of planetary bases and sites
- Number of L&L pads
- ➡ Launch and landing rates
- Facilities and services
- Surface support equipment
- Thermal considerations for storable propellants
- L&L operational scenarios

## Launch and Landing Rates
## Architectures I thru IV

The maximum number of launches and landings for Architectures I and II will be:

- Two lunar landings (2 piloted vehicles ) and two lunar launches (2 piloted vehicles) per year.
- Two Mars landings (1 cargo lander and 1 piloted vehicle) and one Mars launch (1 piloted vehicle) per year.

Architecture III will have the maximum planetary launch and landing rate. The maximum lunar rate will occur during the Mars Dress Rehearsal missions in 2009, with five landings (1 Cargo Lander and 4 Piloted Vehicles) and four launches (4 Piloted Vehicles).

# Launch and Landing Rates
# Architectures I thru IV

- Architectures I and II maximum planetary launch and landing rates
  - Lunar missions
    - Landings - two per year (2 piloted vehicles )
    - Launches - two per year (2 piloted vehicles)
  - Mars missions
    - Landings - two per year (1 cargo lander and 1 piloted vehicle)
    - Launches - one per year (1 piloted vehicle)
- Architecture III maximum lunar launch and landing rates
  - Max rate for lunar missions occurs during the Mars Dress Rehearsal missions in 2009
    - Landings - five per year (1 cargo lander and 4 piloted vehicles)
    - Launches - four per year (4 piloted vehicles)

## Launch and Landing Rates
## Architectures I thru IV (Continued)

The maximum launch and landing rates for Architecture III Mars missions will be two landings (1 cargo lander and 1 piloted vehicle) and one launch (1 piloted vehicle) per year. The normal rate for Architecture III lunar missions (2011-2020) will be four landings (1 cargo lander and 3 piloted vehicles) and three launches (3 piloted vehicles) per year.

The maximum launch and landing rate for Architecture IV will be three lunar landings (1 cargo lander and 2 piloted vehicles) and two lunar launches (2 piloted vehicles) per year. For Mars missions the maximum rate is two landings (1 cargo lander and 1 piloted vehicle), and one launch (1 piloted vehicle) per year.

# Launch and Landing Rates
# Architectures I thru IV (Continued)

- Architecture III maximum Mars launch and landing rates
  - Mars missions
    - Two landings per year (1 cargo lander and 1 piloted vehicle)
    - One launch per year (1 piloted vehicle)
- Architecture III normal rate for lunar missions
  - Normal rate for lunar missions (2011 -2020)
    - Four landings per year (1 cargo lander and 3 piloted vehicles)
    - Three launches per year (3 piloted vehicles)
- Architecture IV
  - Lunar missions
    - Three landings per year (1 cargo lander and 2 piloted vehicle)
    - Two launches per year (2 piloted vehicles)
  - Mars missions
    - Two landings per year (1 cargo lander and 1 piloted vehicle)
    - One launch per year (1 piloted vehicle)

## Launch and Landing Rates
## Architectures I thru IV Summary

The next chart on page A-46 summarizes launch and landing rates for all architectures.

# Launch and Landing Rates Summary

| Architecture | Max Landings L&L per Year | Max Launches L&L per Year | Max Combined L&L per Year | Remarks |
|---|---|---|---|---|
| I Lunar | 2 piloted | 2 piloted | 4 | Maximum L&L rate occurs during Mars Dress Rehearsal when Mars crew and observation crew arrive and leave the surface in 2009. |
| I Mars | 2 (1 cargo & 1 piloted) | 1 piloted | 3 | |
| II Lunar | 2 (1 cargo & 1 piloted) | 2 piloted | 4 | Maximum L&L rate occurs after the Mars Dress Rehearsal. When the observation crew leaves the surface in 2010, one cargo lander arrives, and one piloted vehicle arrives and leaves. |
| II Mars | 2 (1 cargo & 1 piloted) | 1 piloted | 3 | |
| III Lunar | 5 (1 cargo & 4 piloted) | 4 piloted | 9 | Maximum L&L rate occurs in 2009 during Mars Dress Rehearsal when Mars crew arrive and leave while normal L&L operations are ongoing. Normal operations involve four landings (one cargo and three piloted) and three piloted launches. |
| III Mars | 2 (1 cargo & 1 piloted) | 1 piloted | 3 | |
| IV Lunar 2011 | 3 (1 cargo & 2 piloted) | 0 | 3 | Maximum landing rate occurs in 2011 when 1 cargo flight lands* and both the Mars Dress Rehearal Crew and Mars Dress Rehearsal observation crew land. |
| 2012 | 0 | 2 piloted | 2 | Maximum launch rate occurs in 2012 when both the Mars Dress Rehearal crew and Mars Dress Rehearsal observation crew leave. |
| Both Years (2011 & 2012) | 3 (Combined 2 year max) | 2 (Combined 2 year max) | 5 (Combined 2 year max) | |
| IV Mars | 2 (1 cargo & 1 piloted) | 1 piloted | 3 | |

* It is assumed that the cargo mission in 2011 supports of the Mars Dress Rehearsal observation crew.

## Analysis of the Synthesis Group Report Architectures
## Results

**Discussed next is planetary facilities and services.**

# Analysis of the Synthesis Group Report Architectures Results

❑ The following charts describe the results of the evaluation with respect to:

- Number of planetary bases and sites
- Number of L&L pads
- Launch and landing rates
- ➡ Facilities and services
- Surface support equipment
- Thermal considerations for storable propellants
- L&L operational scenarios

## Facilities and Services

Facilities and services provided specifically for launch and landing operations are not identified in the Synthesis Group Report. However, facilities and services will be required for any sustained launch and landing operation from the surfaces of the Moon and Mars. These requirements are identified in the following chart.

# Facilities and Services
# Requirements for L&L Operations

❑ Facilities and Services

- Facilities and services provided specifically for launch and landing operations are not identified in the Synthesis Group Report

❑ Facilities required specifically for launch and landing operations include:

- Launch and landing pads
- Habitat for crew members
- Pressurized work area
  - Workbench for minor repairs
  - Hand tools

❑ Services required specifically for launch and landing operations include:

- Transportation service from the launch site to and from the habitat
  - For surface crews during launch and landing operations (it is assumed that unpressurized and/or pressurized rovers can provide this service)

- Construction services to remove obstacles from L&L pads

## Analysis of the Synthesis Group Report Architectures Results

Discussed next is surface support equipment.

# Analysis of the Synthesis Group Report Architectures Results

- The following charts describe the results of the evaluation with respect to:
  - Number of planetary bases and sites
  - Number of L&L pads
  - Launch and landing rates
  - Facilities and services
  - ➡ Surface support equipment
  - Thermal considerations for storable propellants
  - L&L operational scenarios

## Surface Support Equipment
## Requirements for L&L Operations

Surface support equipment provided specifically for launch and landing operations is not identified in the Synthesis Group Report. However, surface support equipment will be required for any sustained launch and landing operations from the surfaces of the Moon and Mars as identified in the following pages. The initial discussion will be the requirement for LEV and MEV Servicers.

For LEVs and MEVs using cryogenic propellants that remain on the planetary surface for durations greater than 30 days, sufficient propellant must be retained in the tanks to allow piloted vehicles to return to low lunar or low Martian orbit for return to Earth. This could be accomplished by using oversized tanks and allowing propellant boiloff to escape into the planetary environment. However, there is a significant mass penalty associated with this approach, and the pollution which it would cause may interfere with other scientific experiments.

Passive thermal insulation and built-in active propellant management systems may suffice to conserve propellant, however, the inherent mass penalty may be unacceptable.

External servicers on the planet surface with an active propellant management system may be required for reusable LEVs and MEVs using cryogenic propellants that remain on the planetary surface for durations greater than 30 days.

An external active propellant management system was recommended for the Option 5a LEVs and MEVs.

# Surface Support Equipment Requirements for L&L Operations

❑ LEV and MEV Servicers

- Servicers for LEVs and MEVs using cryogenic propellants

  - Sufficient propellant must be retained in the tanks to allow piloted vehicles to return to low lunar or low Martian orbit for return to Earth

  - The mass penalty associated with passive thermal insulation and built-in active propellant management systems may be unacceptable

  - External servicers on the planet surface with an active propellant management system may be required for reusable LEVs and MEVs using cryogenic propellants that remain on the planetary surface for durations greater than 30 days

  - An external active propellant management system was recommended for the Option 5a LEVs and MEVs

# Surface Support Equipment
## Requirements for L&L Operations (Continued)

A different type servicer may be required to maintain the propellant in a liquid state for LEVs and MEVs that would remain on the planetary surface longer than 14 days and use storable propellants. Propellants referred to as "storable" are actually earth storable and the planetary thermal environmental must be considered for storable propellants. For example, temperatures during the the lunar day exceed the boiling point of some of the storable propellants currently in use and nighttime low temperatures are below the freezing point of these propellants. A discussion on planetary thermal environmental considerations with respect to storable propellants is provided is this report starting on page A-72

# Surface Support Equipment Requirements for L&L Operations (Continued)

- Servicers for LEVs and MEVs using storable propellants
  - -- A different type servicer may be required for LEVs and MEVs that remain on the planetary surface longer than 14 days and use storable propellants
  - -- Propellants referred to as "storable" are actually earth storable and the planetary thermal environmental must be considered for storable propellants
  - -- For example, temperatures during the the lunar day exceed the boiling point of some of the the storable propellants currently in use and nighttime low temperatures are below the freezing point of these propellants
  - -- A discussion on planetary thermal environmental considerations with respect to storable propellants is provided is this report starting on page A-72

## Surface Support Equipment
## Requirements for L&L Operations (Continued)

An LEV with an exposed area of approximately 250 square meters, could expect an average of 750 strikes per year by micrometeoriods of 6-10 grams or greater*. The Space Station Freedom Program requirements specify that protection should be provided to attain a 0.9995 probability of no micrometeoriod penetration per year. A similar requirement for LEVs would seem reasonable. In addition, on the lunar surface, the sun's vertical rays provide 442 BTU/hr/square foot of surface area.

Four options for thermal and micrometeoriod protection were identified and evaluated during the Lunar Transportation, Facilities and Operations Study (See Lunar Transportation, Facilities and Operations Study - Option 1, Annual Report, May 1991). The protection methods considered were:

- o Consolidated Vehicle (protection included as part of the flight vehicle design).
- o A-Frame Tent
- o Vehicle Skirt
- o Storage Facility (Fixed and mobile)

Navigation aids (electronic and/or visual) will be required to permit the precision necessary for piloted vehicles to avoid obstacles such as the habitat, communication towers and cargo vehicles that are already on the surface, and to land on relatively small (50 meter diameter) prepared pads.

* "Design of Lunar Colony," University of Houston, NASA- MSC and Rice University Study, NASA/ASSE System Design Institute, June 1967.

# Surface Support Equipment Requirements for L&L Operations (Continued)

- ❑ Thermal and Mircometeoroid Protection
  - An LEV with an exposed area of approximately 250 square meters, could expect an average of 750 strikes per year by micrometeoriods*
  - On the lunar surface, the sun's vertical rays provide 442 BTU/hr/square foot of surface area
  - Four options for thermal and micrometeoriod protection were identified and evaluated during the Lunar Transportation, Facilities and Operations Study
    - o Consolidated Vehicle
    - o A-Frame Tent
    - o Vehicle Skirt
    - o Storage Facility (Fixed and mobile)
- ❑ Navigation aids (electronic and/or visual)
  - Aids will be required to permit piloted vehicles to avoid surface obstacles and to land on relatively small (50 meter diameter) prepared pads.

* "Design of Lunar Colony," University of Houston, NASA - MSC and Rice University Study, NASA/ASSE System Design Institute, June 1967.

## Surface Support Equipment
## Requirements for L&L Operations (Continued)

Other miscellaneous surface support equipment (dependent on LEV and MEV design) is listed on the facing chart.

# Surface Support Equipment Requirements for L&L Operations (Continued)

- ❑ Other miscellaneous surface support equipment (dependent on LEV and MEV designs)
  - Auxiliary Lghting Equipment
  - Access Equipment
  - Waste Management Servicing System
  - ECLSS Service System
  - Fuel Cell Service System

## Surface Support Equipment
## Requirements for L&L Operations (Continued)

Based on the Architectures described in the 90-Day Report and a baseline cryogenic, reusable LEV surface support equipment for launch and landing operations was recommended to MASE during the trade studies in 1990. Page A-62 lists the equipment recommended.

Applicability of the surface support equipment recommended to MASE during the trade studies in 1990 to the architectures described in the synthesis group report is summarized on page A-110

# Surface Support Equipment Requirements for L&L Operations (Continued)

- Surface support equipment recommended to Level III and IV during MASE trade studies are as follows:
  - LEV and MEV Servicer (includes the following)
    - Cryogenic Propellant Management
    - Thermal Control
    - Electrical Power
    - Data Management, Command and Control System
  - Thermal/Micrometeoroid Protection
  - Waste Management System
  - ECLSS Service System
  - Fuel Cell Service System
  - Lunar LOX Pallet
  - Auxiliary Lighting Equipment
  - Navigation Aids
  - Access Equipment
  - Engine Blast Protection
  - Data Management and Communication System (Habitat)
  - Command and Control Telemetry Link (Earth to planetary surface)
- Applicability to Architectures I thru IV is shown in the chart on page A-110

# Surface Support Equipment
# Purpose and Function

The following charts describe the purpose and function of the surface support equipment recommended during the MASE trade studies.

# Surface Support Equipment
# Purpose and Function

- Servicers for LEVs and MEVs using cryogenic propellants
  - Cryogenic Propellant Management System captures and reliquifies gaseous $H_2$ and $O_2$ through reliquefaction or uses refrigeration to preclude loss of the propellant supply while the LEV and MEV is stored on the planetary surface.
- Servicers for LEVs and MEVs using storable propellants
  - Storable Propellant Thermal Conditioning System provides heating or cooling as required to maintain propellants in a liquid state and to prevent boiloff or freezing
- Servicers include:
  - Thermal Control Unit to dissipate heat generated by LEV and MEV systems while operating from surface system servicers.
  - Electrical Power Unit to operate electrically driven systems, power tools, equipment, and LEV and MEV systems at the L&L pads.
  - Data management, Command and Control System to monitor and control various servicer systems either in a manual or automatic mode

# Surface Support Equipment
# Purpose and Function (Continued)

**The purpose and function of Surface Support Equipment (SSE) continued on the facing page.**

# Surface Support Equipment
# Purpose and Function (Continued)

- Thermal and Micrometeoroid Protection required to protect LEV from direct and reflected solar radiation during the lunar day and provide some degree of micrometeoroid protection. Similar cover may be required for MEV to provide protection from Martian dust storms.
- Waste Management System to deservice waste holding tanks and clean and sanitize the system(s). Must also provide for waste disposal.
- ECLSS Service System to service, deservice, circulate, and filter fluids used in the LEV and MEV Environmental Control and Life Support System.
- Fuel Cell Service System - Required to service, deservice LEV and MEV fuel cell oxygen, hydrogen and water tanks.
- Lunar LOX Pallet to transport lunar LOX from in situ production plant to LEV.
- Auxiliary Lighting Equipment to provide auxiliary lighting for surface operations.
- Navigations Aids (electronic and visual) to ensure landing at the proper pad or site.

## Surface Support Equipment
## Purpose and Function (Continued)

The purpose and function of Surface Support Equipment (SSE) continued on the facing page.

# Surface Support Equipment
# Purpose and Function (Continued)

- ❑ Access Equipment for internal and external access to LEV and MEV for inspection, maintenance, and servicing.
- ❑ Engine Blast Protection at permanent bases to protect surface systems and facilities from ejecta generated during LEV and MEV launch and landing.
- ❑ Data Management and Communication System (Habitat) for the control of application software for the test and checkout of the LEV and MEV while on the surface. Must include monitoring and evaluation capability. Interfaces with Command and Control Telemetry Link for data exchange with and display of data from other base systems and similar Earth systems.
- ❑ Command and Control Telemetry Link provides the communication link required for data exchange with and display of data from the LEV and MEV and other base systems and similar Earth systems.

# Surface Support Equipment
# Purpose and Function (Continued)

The purpose and function of Surface Support Equipment (SSE) continued on the facing page.

# Surface Support Equipment
# Purpose and Function (Continued)

- Additional surface support equipment
  - Device to move expended descent stages (piloted or cargo) could take the following forms
    - LEV Payload Unloader (LEVPU) described in PSS Element Database as a three strut supercrane
    - Forklift Handler
    - Tow Truck with either wheels or skids that can be attached to vehicles or wheels or skids provided as part of vehicle
  - Range Safety Command (RSC) System under control of base crew for Architecture III
    - Used to redirect (or destroy) errant cargo landers which may threaten the manned base

## Analysis of the Synthesis Group Report Architectures
## Results

The next subject for discussion is thermal consideration with regard to the environment of the Moon and Mars, and the use of storable propellents.

# Analysis of the Synthesis Group Report Architectures Results

- The following charts describe the results of the evaluation with respect to:
  - Number of planetary bases and sites
  - Number of L&L pads
  - Launch and landing rates
  - Facilities and services
  - Surface support equipment
  - ➡ Thermal considerations for storable propellants
  - L&L operational scenarios

## Thermal Environmental Considerations for Storables

Often comparisons between cryogenic and storable propellant LEVs and MEVs ignore planetary thermal environmental conditions with respect to the storable propellant. If tank pressure was to be maintained at one atmosphere (14.7 pisa), storable propellants would boil, because the maximum lunar temperature exceeds the boiling point of the storable propellants that are being considered for use. Also, except for methane, the minimum lunar temperature is below the freezing point of all storable propellants that are being considered for use.

The minimum Martian temperature is also below the freezing point of most of the storable propellants that are being considered for use, but exceeds the boiling point of methane.

# Thermal Environmental Considerations for Storables

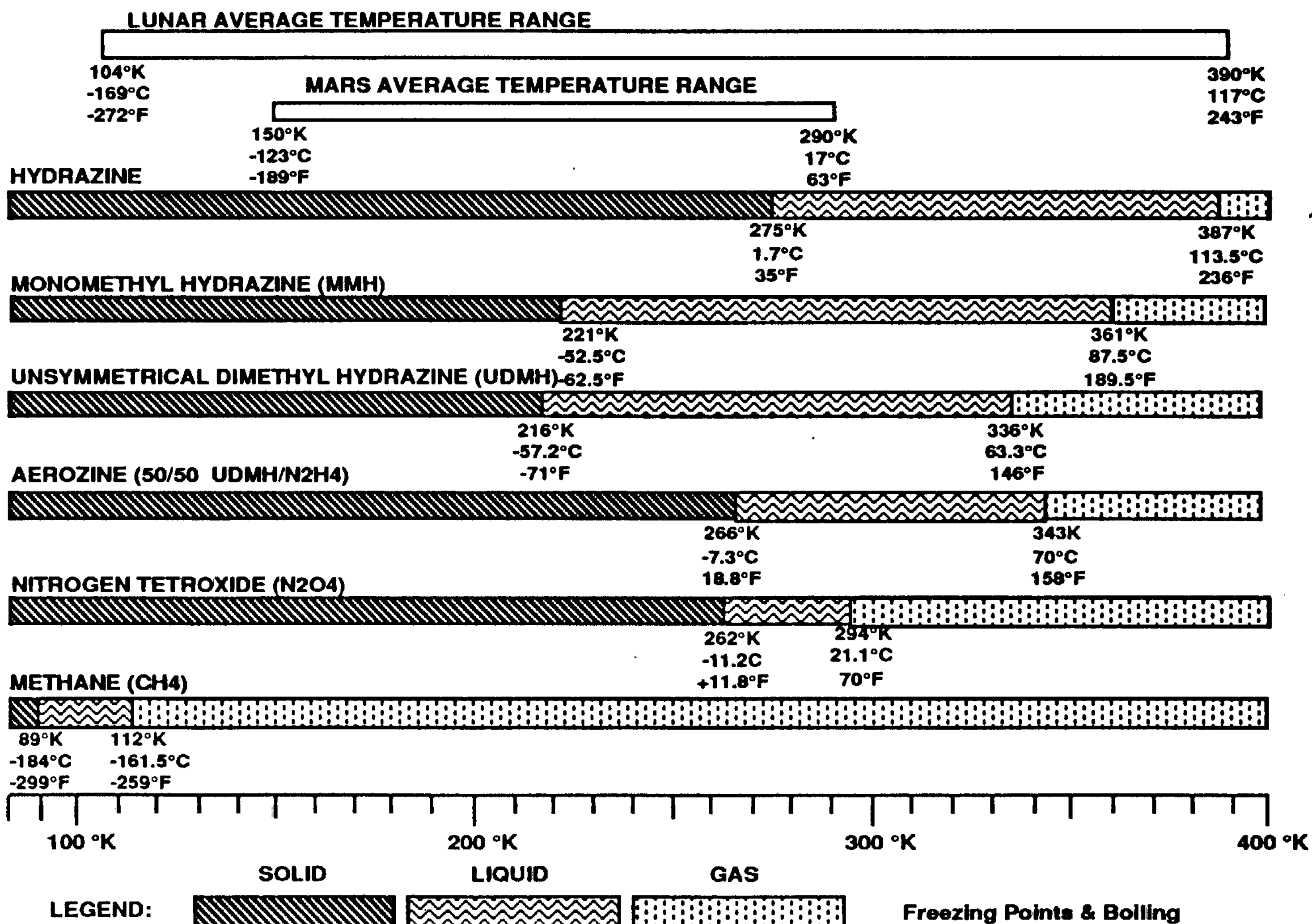
- Comparisons between cryogenic and storable propellant for LEVs and MEVs must include planetary thermal environmental conditions with respect to the storable propellant. At a pressure of one atmosphere:
  - Maximum lunar temperature exceeds the boiling point of storable propellants being considered for use
  - Minimum lunar temperature is below the freezing point of storable propellants being considered for use, except methane
  - Minimum Martian temperature is below the freezing point of most storable propellants being considered for use, and exceeds the boiling point of methane

## Thermal Environmental Considerations
## Storable Propellant State Compared to Planetary Thermal Environment

The temperature extremes for the Moon and Mars, as well as the boiling point and freezing point for popular storable propellants, at a pressure of 14.7 psia, is shown on the facing chart.

# Thermal Environmental Considerations

## Storable Propellant State Compared to Planetary Thermal Environment




Freezing Points & Boiling Points are given for an ambient pressure of 14.7 PSIA

## Thermal Environmental Considerations
## Passive Methods for Thermal Protection

Multi-Layer Installation (MLI ) ,approximately 1 inch thick, coupled with the inherent thermal lag of the propellant, may be sufficient to prevent storable propellant freezing.

Increasing tank pressure may be one method of reducing or preventing propellant boiloff, however, curves for vapor pressure as a function of temperature for storable propellants, indicate that for some propellants, the required pressures would be high. For example, tank pressure to maintain nitrogen tetroxide in a liquid state would be approximately 33 atm (485 psia) at the maximum lunar temperature. At the other extreme, a more reasonable tank pressure of ~2.3 atm (34 psia) is needed to maintain monomethyl hydrazine in a liquid state.

# Thermal Environmental Considerations
# Passive Methods for Thermal Protection

- ❑ MLI (1 inch thick) coupled with the inherent thermal lag of the propellant may be sufficient to prevent storable propellant freezing*
- ❑ Increasing tank pressure would be one method of reducing or preventing propellant boiloff
  - Curves for vapor pressure as a function of temperature for storable propellants indicate that that pressures would be high
    - -- Tank pressure to maintain nitrogen tetroxide in a liquid state ~ 33 atm
    - -- Tank pressure to maintain monomethyl hydrazine in a liquid state ~2.3 atm

* Preliminary calculations by Ray Lacovic, NASA-LeRC.

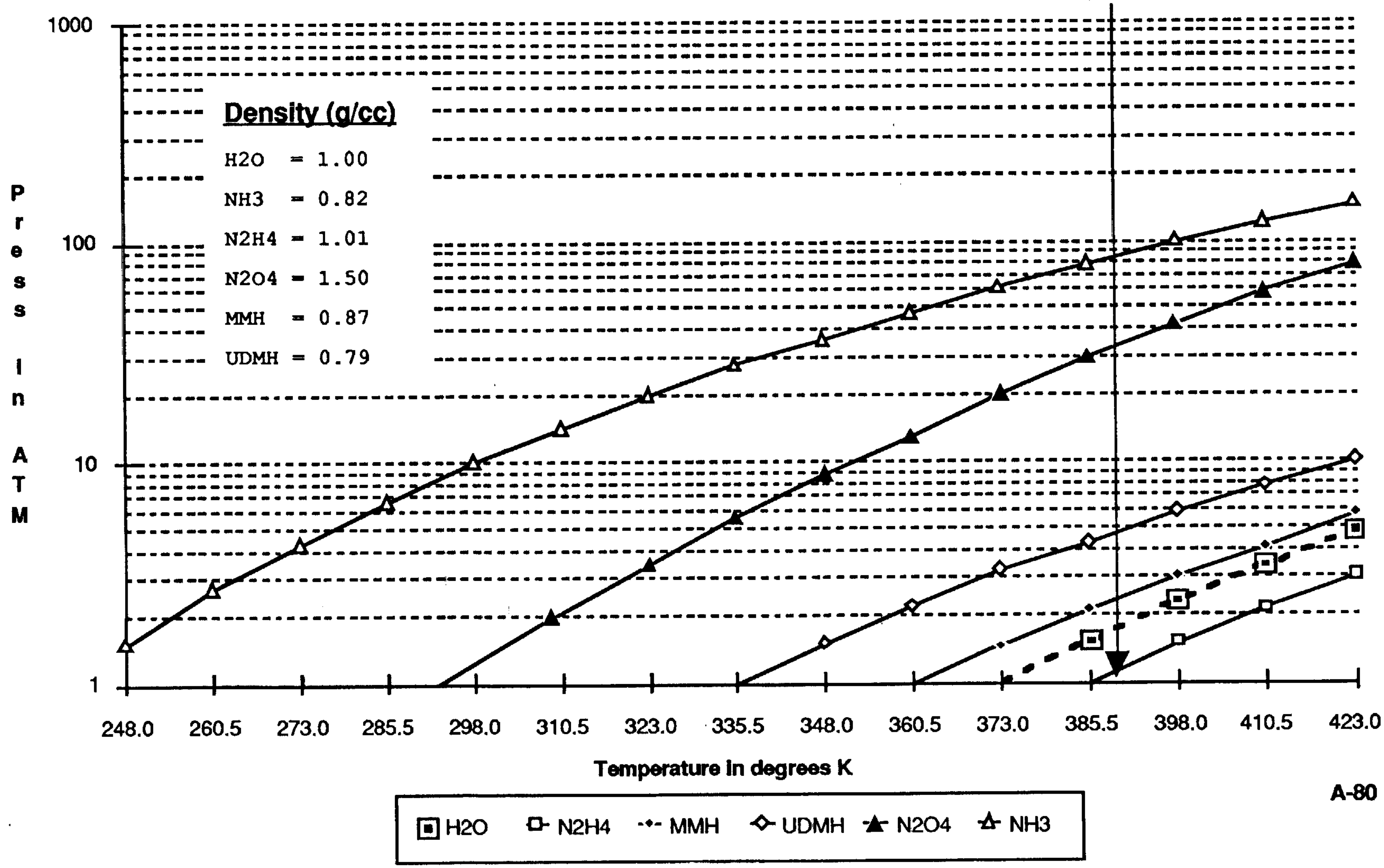
Based on a spherical tank 8 ft in diameter containing 25,000 lbs N2O4 with an initial temperature of +62°F and considering a Lunar Day/Night cycle between temperature extremes of +243F and -272F . Predicted propellant differential decrease after one cycle was -10°F.

## Thermal Environmental Considerations
## Vapor Pressure as a Function of Temperature

**The following chart shows curves for vapor pressure as a function of temperature for storable propellants.**

# Thermal Environmental Considerations
# Vapor Pressure as a Function of Temperature

## ❑ Vapor pressure vs temperature

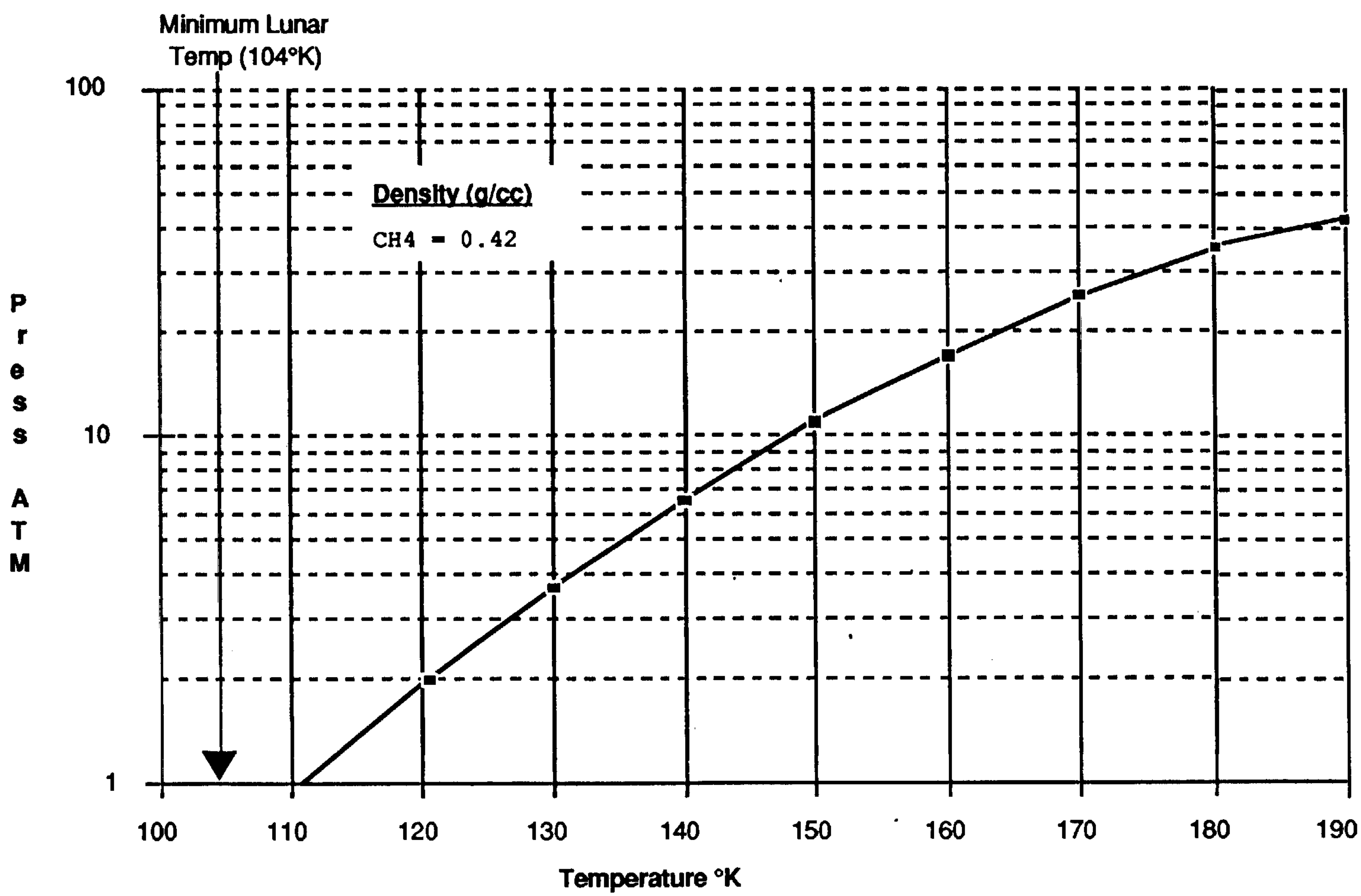


# Thermal Environmental Considerations
## Vapor Pressure as a Function of Temperature (Continued)

A curve for vapor pressure as a function of temperature for methane at temperatures above the lunar minimum is shown in the facing chart.

# Thermal Environmental Considerations
# Vapor Pressure as a Function of Temperature (Continued)

- ❑ Vapor pressure vs temperature for methane



## Analysis of the Synthesis Group Report Architectures Results

**The next subject for discussion is the launch and landing operational scenarios.**

# Analysis of the Synthesis Group Report Architectures Results

- ❑ The following charts describe the results of the evaluation with respect to:
  - Number of planetary bases and sites
  - Number of L&L pads
  - Launch and landing rates
  - Facilities and services
  - Surface support equipment
  - Thermal considerations for storable propellants
  - ➡ L&L operational scenarios

C-2

## Launch and Landing Scenarios
## Architectures I thru IV

Launch and landing scenarios for Option 5a were developed for PSS as support for the 90 Day study*. Each operation within a scenario was supported by detailed functional task flows. Launch and landing scenarios for the early lunar missions of Architectures I thru IV would be essentially the same as early Option 5a manned missions. Launch and landing scenarios for Architectures I, II and IV long duration lunar missions would be the same as the Option 5a manned operational missions. Scenarios for Architecture III operational lunar missions with the permanently manned lunar base would be similar to the original baseline scenario developed during the initial phase of LTFOS**

The initial turnaround for the first piloted missions of Architecture I and III are different from later missions, because this first crew must set up and check out the initial base. This is essential for the follow-on missions where the crew members live and work at the base. Cargo removal, therefore, is one of the most important L&L operations on these initial missions.

* Based on Reference Architecture Description, Option 5a (Option 5 with ISRU Emphasis), PSS Document 90-2, May 1990

** Lunar Transportation, Facilities and Operations Study, Final Report, April 1990.

# Launch and Landing Scenarios Architectures I thru IV

- Launch and Landing Scenarios for Option 5a were:
  - Developed for PSS as support for the 90 Day study*
  - Supported each operation by detailed functional task flows
- Launch and Landing scenarios for Architectures I thru IV early lunar missions would be the same as early Option 5a manned missions
- Launch and Landing scenarios for Architectures I, II and IV long duration lunar missions would be the same as the Option 5a manned operational missions
- Scenarios for Architecture III operational lunar missions with the permanently manned lunar base would be similar to the original baseline scenario developed during the initial phase of LTFOS**
- The initial turnaround for the first piloted missions of Architecture I and III:
  - Are different from later missions, because this first crew must set up and check out the initial base
  - Cargo removal is a very important L&L operation on these missions

* Based on Reference Architecture Description, Option 5a (Option 5 with ISRU Emphasis), PSS Document 90-2, May 1990



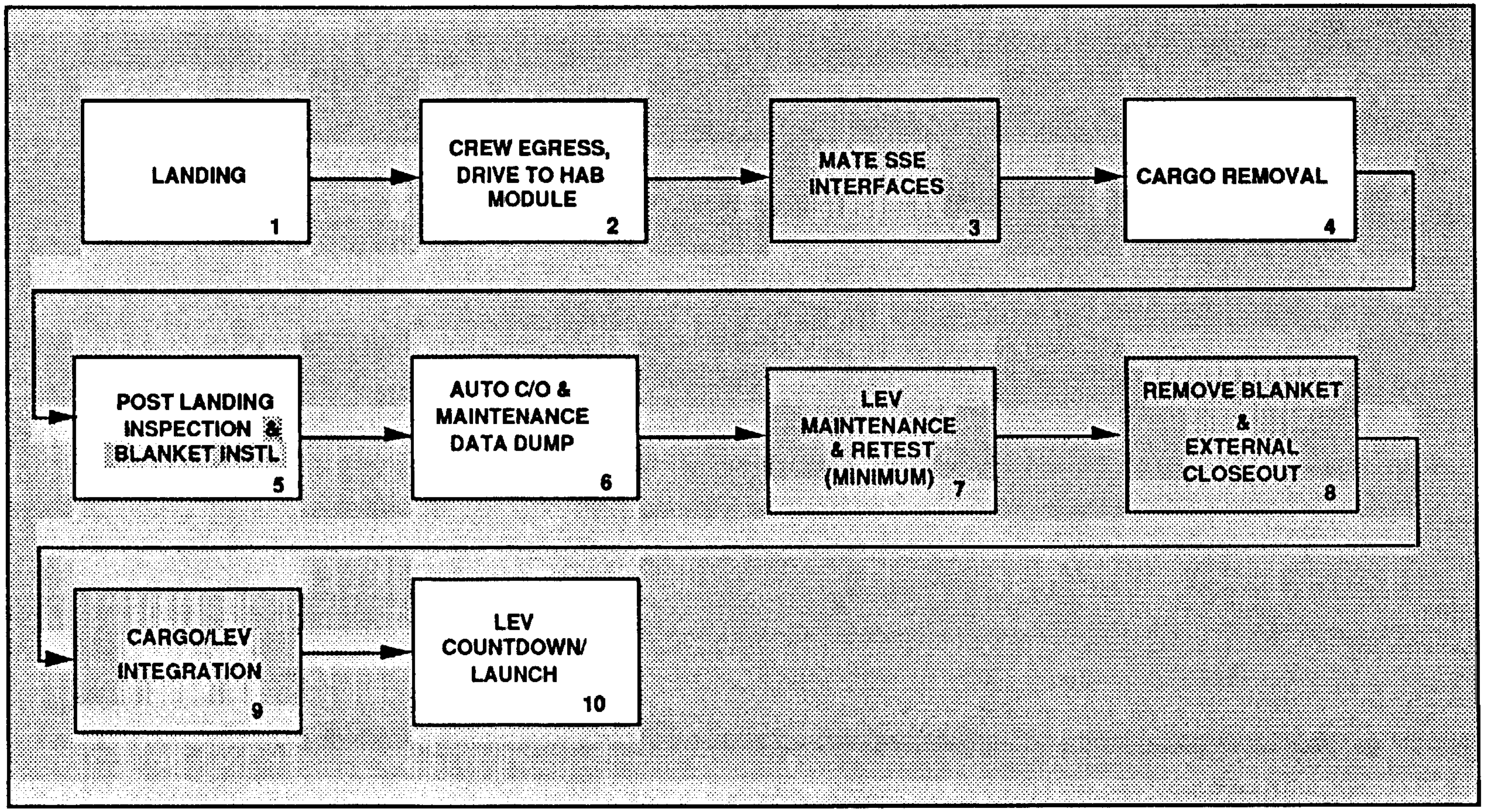
** Lunar Transportation, Facilities and Operations Study, Final Report, April 1990.

## Launch and Landing Scenarios
## Early Lunar Missions

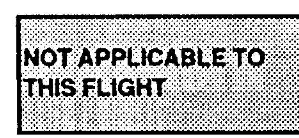
The facing chart shows the launch and landing scenario for the early lunar missions of Architectures I thru IV.

# Launch and Landing Scenarios
# Early Lunar Missions

- ❑ Scenario for early lunar missions of Architectures I thru IV*




* Based on Reference Architecture Description, Option 5a (Option 5 with ISRU Emphasis), PSS Document 90-2, May 1990.

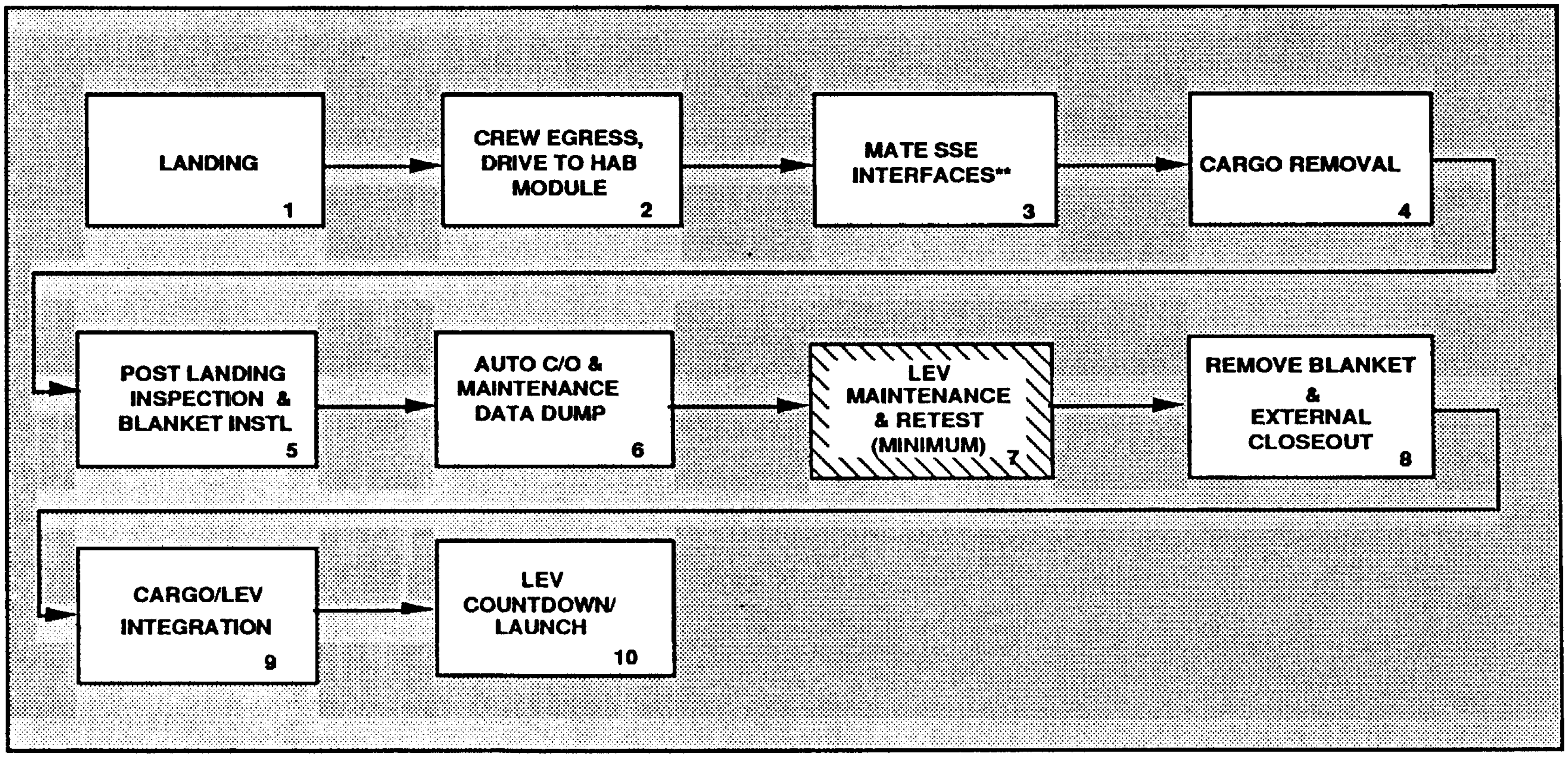


## Launch and Landing Scenarios
## Longer Lunar Missions

The facing chart shows launch and landing scenario for the longer duration lunar missions of Architectures I thru IV.

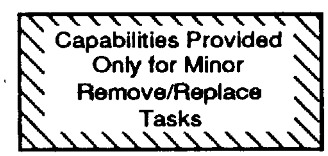
# Launch and Landing Scenarios
# Longer Lunar Missions

- Scenario for Architectures I, II and IV longer duration lunar missions*




* Based on Reference Architecture Description, Option 5a (Option 5 with ISRU Emphasis), PSS Document 90-2, May 1990.

** Assumes SSE has been delivered and is ready for use.

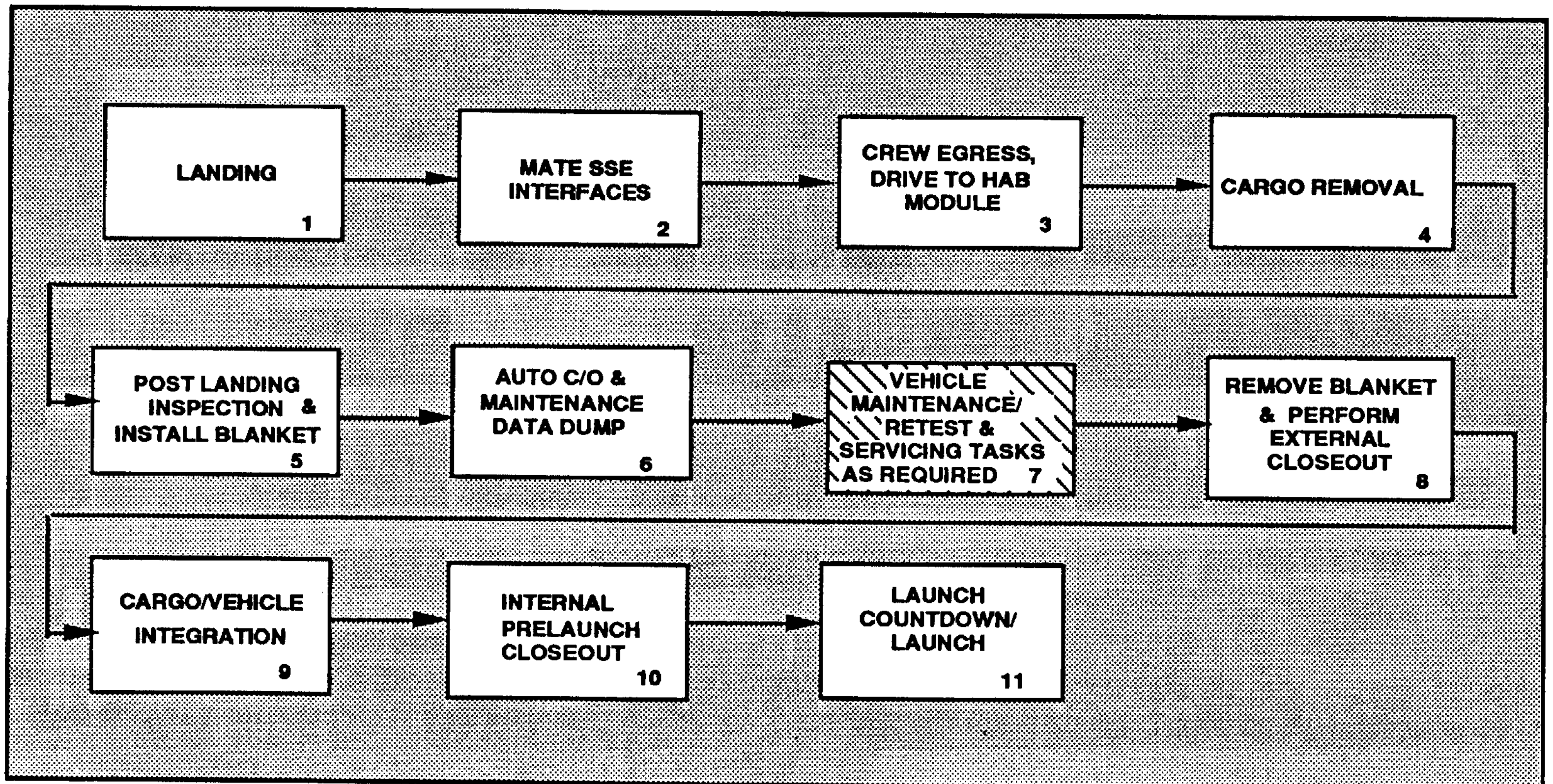


## Launch and Landing Scenarios
## Permanently Manned Lunar Base

The launch and landing scenario for the permanently manned base of Architecture III is shown on the facing chart.

# Launch and Landing Scenarios
# Permanently Manned Lunar Base

- Scenario for Architecture III operational lunar missions with the permanently manned lunar base




* Assumes Lunar Base is permanently manned & a dedicated surface crew is available to perform L&L operations.

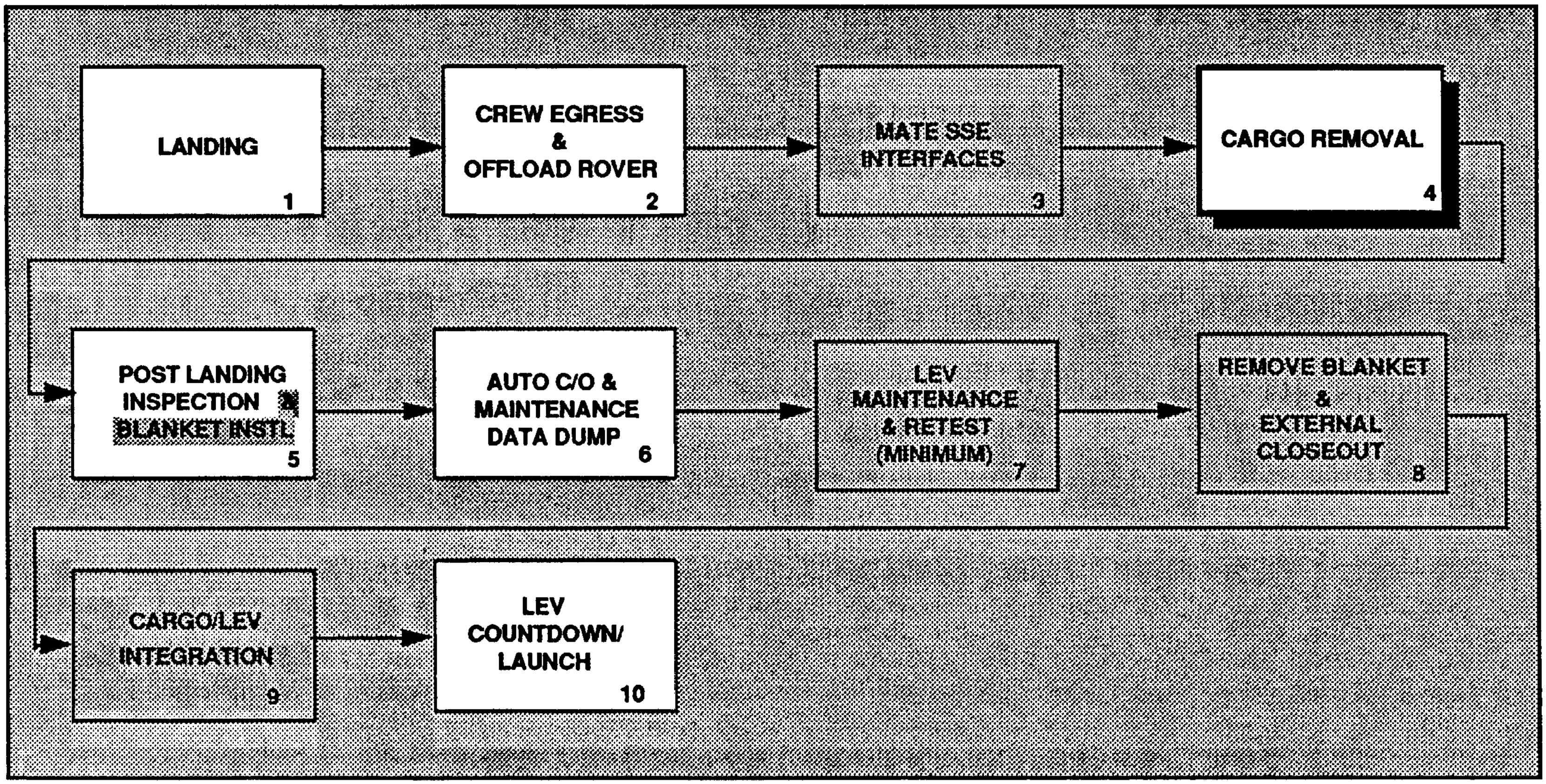
Capabilities Provided Only for Minor Remove/ReplaceTasks

## Launch and Landing Scenarios
## First Piloted Lunar Mission of Architecture I

The facing chart shows the launch and landing scenario for the first lunar missions of Architecture I . Cargo removal is highlighted, because it is one of the most important operations on this mission, and is discussed in the following charts.

# Launch and Landing Scenarios
# First Piloted Lunar Mission of Architecture I

- ❑ **Scenario for the first piloted mission of Architecture I in 2005**




* Assumes the first cargo mission (LTV-C1) was successful and the first piloted mission (LTV-P1) landed in the vicinity of the cargo lander.

NOT APPLICABLE TO THIS FLIGHT

## Launch and Landing Scenarios
## First Piloted Lunar Mission of Architecture I

The following chart lists the cargo that would be on the first cargo lander, and the cargo that would be on first piloted vehicle of Architecture I.

# Launch and Landing Scenarios
# First Piloted Lunar Mission of Architecture I

❑ **Manifest for the first Cargo Lander and the first Piloted Mission of Architecture I in 2005**

- One Cargo Lander
  - Habitat
  - Electrical Power System
  - Cryogenic-tank Test Set
  - Unloader*
  - Consumables
- One Piloted Vehicle
  - Orbiter
  - Lander
  - Unpressurized Rover
  - Solar Flare Detector
  - Consumables

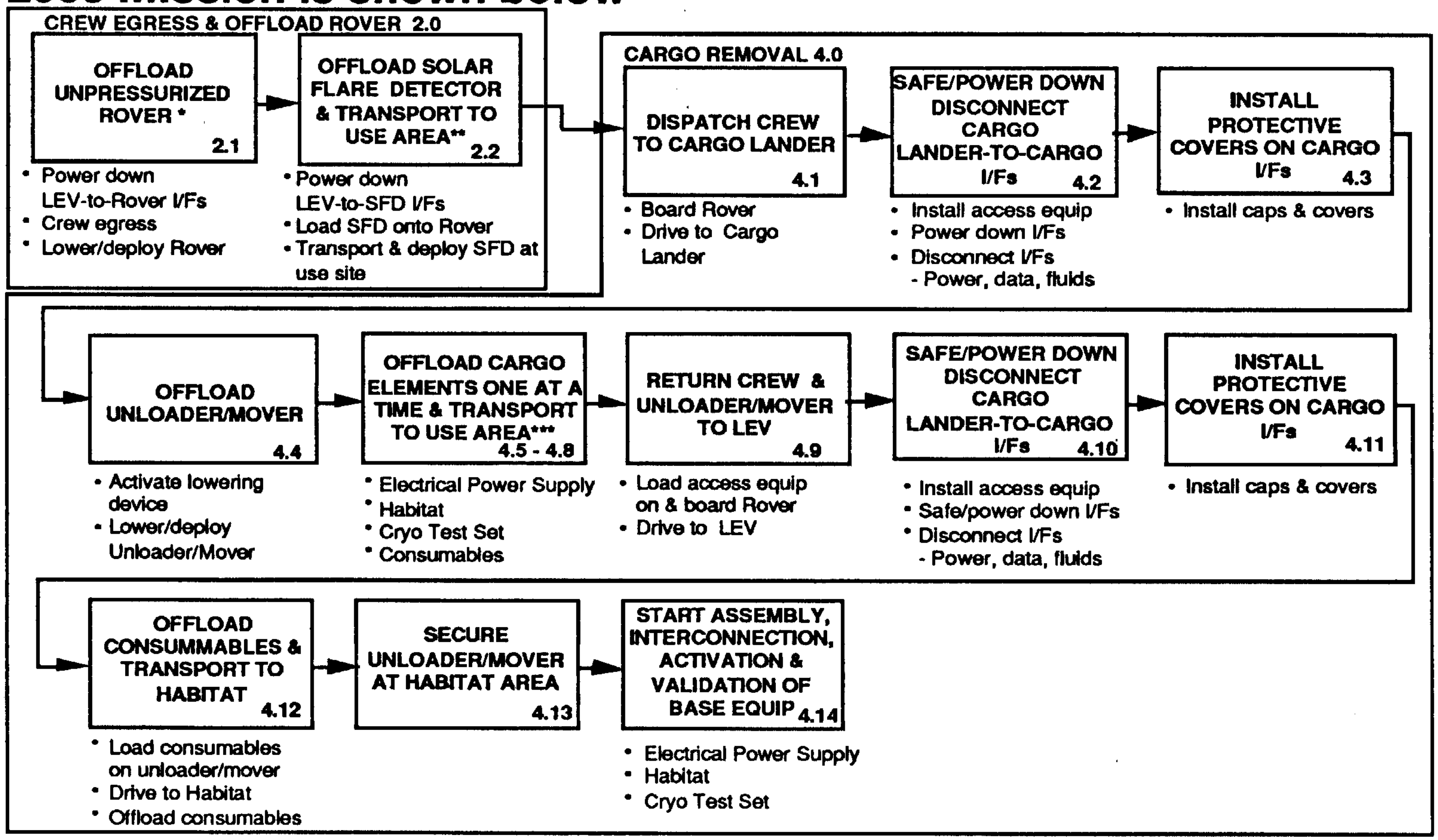
* Assumed that unloader is also a mover.

## Launch and Landing Scenarios
## Cargo Removal Functional Flow

As stated earlier, cargo removal is one of the most important L&L operations on the initial missions of Architectures I and III, because it establishes the operating base for the follow-on missions. For this reason, a detailed functional flow for this operation was developed and is shown in the next chart.

# Launch and Landing Scenarios Functional Flow

- A sample functional flow diagram for cargo removal Architecture I 2005 mission is shown below




* Assumes devices on LEV & Cargo Lander allow the automatic lowering of Rover & Unloader/Mover.

** Assumes Solar Flare Detector (SFD), has self contained power supply, can be offloaded mannually and transported with the Rover.

*** These are four serial tasks



**Note: Solar Flare Detector (SFD) is removed and deployed first, because it affects crew safety.**

## Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

This section presents conclusions of the report, and provides some recommendations based on the assessment.

# Analysis of the Synthesis Group Report Architectures and Impacts on PSS Launch and Landing Operations

## Agenda

- Purpose and Approach
- Assumptions
- Ground Rules
- Results
- ➡ Conclusions and Recommendations

## Conclusions and Recommendations
### Architectures I, II and IV Lunar Missions

There is no need for a large infrastructure for the lunar missions of Architectures I, II and IV. Minimal facilities, services and SSE* are required for these missions, because there are only a few missions of relatively short duration. One pad with minimal navigation aids should be sufficient for piloted launches and landings. However, thermal and micrometeoroid protection will be required, as well as an LEV Servicer (i. e., thermal conditioning system for storable propellants, or propellant management system for cryogenic propellants).

It is recommended that the LEV onboard computers and BIT/BITE for LEV and Servicer checkout be used for test, checkout and monitoring of the performance of the LEV and Servicer. Also, it is recommended that the standard mission communications links be used to meet all L&L operations, earth-to-LEV, LEV-to-base and base to earth communication requirements. Other standard mission equipment should be used for crew surface transport and cargo surface handling and transport.

The L&L scenarios for Architectures I, II and IV would be essentially the same as those developed for Option 5a of the 90 Day Study.

* See SSE Summary chart on page A-110

# Conclusions and Recommendations Architectures I, II and IV Lunar Missions

- ❑ Architectures I, II and IV Lunar Missions - No large infrastructure required (Minimal facilities, services and SSE*)
  - One pad for piloted launches and landings
  - Minimal navigation aids (e. g., transponders on cargo landers on the surface to serve as beacons for arriving piloted LEVs)
  - Provide thermal/micrometeoroid protection
  - LEV Servicer (i. e., thermal conditioning system for storable propellants or propellant management system for cryogenic propellants)**
  - Use LEV onboard computers and BIT/BITE for LEV and Servicer checkout
  - Use standard mission communications links to meet all L&L operations, earth-to-LEV, LEV-to-base and base to earth communication requirements
  - Use standard mission equipment for crew surface transport and cargo surface handling and transport
  - L&L scenarios same as Option 5a

* See SSE Summary chart on page A-110
** Assumes that allowing propellants to boil off for up to 180 days, with loss of propellant while polluting the lunar environment, is an unacceptable solution.

## Conclusions and Recommendations
### Architecture III Lunar Missions

A large L&L infrastructure will be required for the lunar missions of Architecture III because under this architecture, the base becomes a permanent L&L complex receiving cargo and replacement crews on a regularly scheduled basis. This will require dedicated facilities, services and a full compliment of SSE*. A minimum of four pads for piloted launches and landings would be required**.

Further studies and experiments should be conducted to develop a better understanding of ejecta effects, and to develop protection techniques for protecting LEVs on the surface from ejecta produced by arriving cargo landers, and arriving and departing piloted vehicles.

# Conclusions and Recommendations (Continued)
# Architecture III Lunar Missions

- Architecture III Lunar Missions - Large L&L infrastructure required (Maximum facilities, services and SSE*)
  - Minimum of four pads for piloted launches and landings**
  - Conduct further studies and experiments to develop a better understanding of ejecta effects
  - Develop protection techniques for LEVs on the surface from ejecta produced by arriving cargo landers and arriving and departing piloted vehicles.
  - Provide electronic and visual navigation aids
  - Provide a shelter or hangar for thermal and micrometeoroid protection
  - Provide at least three LEV Servicers (i. e., thermal conditioning system for storable propellants or propellant management system for cryogenic propellants)
  - Use the base computers in conjunction with LEV onboard computers and BIT/BITE for LEV and Servicer checkout, health monitoring, trend analysis

* See SSE Summary chart on page A-110

** A maximum of 63 landing sites may be required if piloted vehicles are two stage expendables (i. e., 17 cargo landers and 46 piloted vehicles).

## Conclusions and Recommendations (Continued)
## Architecture III Lunar Missions

**Recommendations for the Architecture III Lunar Missions are continued on the next chart.**

# Conclusions and Recommendations
# Architecture III Lunar Missions (Continued)

- ❑ Architecture III Lunar Missions - (Continued)
  - Provide dedicated communications links to meet all L&L operations communication, earth-to-LEV, LEV-to-base and base-to-earth requirements
  - Provide dedicated equipment for crew surface transport, cargo surface handling and transport
  - Assign L&L operations as the primary responsibility of at least three crew members
  - Employ L&L scenarios similar to LTFOS baseline*

* Lunar Transportation, Facilities and Operations Study, Final Report, April 1990.

## Conclusions and Recommendations (Continued)
## Architectures I thru IV Mars Missions

There is no requirement for a large infrastructure for Architectures I thru IV Mars Missions. Minimal facilities, services and SSE are required for these missions because of the small number of missions. One pad with minimal navigation aids should be sufficient for piloted launches and landings. Some form of thermal/micrometeoroid and blown dust protection may be required. A MEV Servicer (I. e., thermal conditioning system for storable propellants or propellant management system for cryogenic propellants)** will be required for the long duration surface stays (600 days).

The MEV onboard computers and BIT/BITE should be sufficient for MEV and Servicer checkout and health monitoring. Standard mission communications links should meet all L&L operations, earth-to-MEV, MEV-to-base and base-to-earth communication requirements. The standard mission equipment should be designed to provide for crew surface transport and cargo surface handling and transport.

It is recommended that L&L operations scenarios be based on the scenarios developed for Option 5a.

# Conclusions and Recommendations (Continued)
## Architectures I thru IV Mars Missions

- Architectures I thru IV Mars Missions - No large infrastructure required (Minimal facilities, services and SSE*)
  - One pad for piloted launches and landings
  - Transponders on cargo landers to serve as navigation aids
  - Provide thermal and micrometeoroid protection
  - MEV Servicer (i. e., thermal conditioning system for storable propellants or propellant management system for cryogenic propellants)**
  - Use MEV onboard computers and BIT/BITE for MEV and Servicer checkout
  - Use standard mission communications links to meet all L&L operations, earth-to-MEV, MEV-to-base and base-to-earth communication requirements
  - Use standard mission equipment for crew surface transport cargo surface handling and transport
  - L&L scenarios same as Option 5a

* See SSE Summary chart on page A-110

** Assumes that allowing propellants to boil off for up to 600 days, with loss of propellant while polluting the Martian environment, is an unacceptable solution.

## Conclusions and Recommendations (Continued)
## Surface Support Equipment Summary

**The facing chart summarizes the SSE, and the applicability of each to the various architectures (i. e., their operational capabilities),**

# Conclusions and Recommendations (Continued)
## Surface Support Equipment Summary

| Launch & Landing Support EquipmentNOC | Architecture I | | | | Architecture II | | | | | | | | | | Architecture III | | | | Architecture IV | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LB 1 1 & ON | MDR NBLB | MB 1 IOC | MB 2 NOC | LB 1 NOC 1 - 3 | LB 2 NOC 4 | LB 3 NOC 4 | LB 4 NOC 4 | LB 5 NOC 4 | MDR NBLB | MB 1 IOC | MB 2 NOC 1 | MB 3 NOC 1 | MB 4 NOC 2 | LB 1 IOC NOC 1 - 4 | MDR NBLB | MB 1 IOC | MB 2 NOC | LB 1 IOC NOC 1 & 2 | MDR NBLB | MB 1 IOC NOC |
| Cryogenic Propellant Servicer<br>Propellant Conditioning<br>Vehicle Thermal Control<br>Electrical Power<br>Data Mgt, Comm. & Control | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD |
| Storable Propellant Servicer<br>Propellant Thermal Control<br>Vehicle Thermal Control<br>Electrical Power<br>Data Mgt, Comm. & Control | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD | PD |
| Thermal/micrometeoroid Shield | A | A | | | A | A | A | A | A | A | | | | | A | A | | | A | A | |
| Waste Management System | | | | | | | | | | | | | | | A | | | | | | |
| ECLSS Service System | | | | A | | | | | | | | | | | A | | | A | A | | A |
| Fuel Cell Service System | | | | A | | | | | | | | | | | A | | | A | A | | A |
| Cryogen Pallet(s) | | | | A | A | | | | | | | | | A | A | | | A | A | | A |
| Auxiliary Lighting Equipment | | | | A | | | | | | | | A | A | A | A | | | A | A | | A |
| Navigation Aids | A | | | | A | | | | | | | | | A | A | | | | A | | A |
| Access Equipment | | | | A | | | | | | | | A | A | A | A | | | A | A | | A |
| Engine Blast Protection | A | | | | A | | | | | | | | | A | A | | | | A | | A |
| Data Management & Communication System (Habitat) | A | A | | A | A | | | | | A | A | A | A | A | A | A | | A | A | A | A |
| Command & Control Telemetry Link(Earth to Surface) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |

Legend:
A = Applicable
IOC = Initial Operational Capability
LB = Lunar Base
MB = Mars Base
MDR = Mars Dress Rehearsal
NBLB = Near By Lunar Base
NOC = Next Operational Capibility
PD = Applies only to the vehicle servicer and is dependent on the propellant used.

# Analysis of the Synthesis Group Report Architectures
## Backup Material

The following pages provide detailed data developed from the NASA/MDSSC Study team's interpretation of the material in the Synthesis Group Report. These data include a summary of the lunar and Mars mission parameters, lunar and Mars mission manifest for Architectures I through IV and a complete cargo manifest for each architecture.

# Analysis of the Synthesis Group Report Architectures Backup Material

- ❑ Lunar Mission Parameters
- ❑ Mars Mission Parameters
- ❑ Synthesis Group Report Lunar/Mars Mission Manifest Architectures I thru IV
- ❑ Cargo Manifest Architectures I, II, III & IV

# Lunar Mission Parameters

| Architecture | Piloted Flight No(s) | Dates | Stay Time (Days) | Crew Size | Base/Site | Ops Phase | Remarks |
|---|---|---|---|---|---|---|---|
| I | 2 & 3 | 2005 & 2006 | 14 | 6 | Lunar Base 1 | IOC | 5 Crew members on surface, 1 in LLO |
| I | 5 | 2007 | 45 -60 | 6 | Lunar Base 1 | NOC-1 | |
| I | 7 | 2009 | 30 | 6 | Nearby Lunar Base 1 | NOC-2 | 6 Crew members at nearby base for Mars dress rehearsal |
| I | 8 | 2009 | 90 | 6 | Lunar Base 1 | NOC-2 | 3 Crew members assigned to observe Mars Dress rehearsal |
| I | 10 & 12 | 2010 - 2011 | - | 6 | Nearby Lunar Base 1 | - | Optional missions for Mars equip. redesign C/O if req'd. |
| II | 1 - 3 | 2003 - 2005 | 14 | 6 | Landing Sites 1, 2 & 3 | IOC | 5 Crew members on surface, 1 in LLO<br>One lunar base site is selected from the 3 Landing Sites |
| II | 5 | 2006 | 90 | 6 | Lunar Base 1 | NOC-1 | |
| II | 7 | 2007 | 180 | 6 | Lunar Base 1 | NOC-2 | |
| II | 9 | 2009 | 30 | 6 | Nearby Lunar Base 1 | NOC-3 | 6 Crew members at nearby base for Mars dress rehearsal |
| II | 10 | 2009 | 90 | 6 | Lunar Base 1 | NOC-3 | 3 Crew members assigned to observe Mars Dress rehearsal |
| II | 12 - 15 | 2010 - 2015 | - | 6 | Lunar Base 2 thru 5 | NOC-4 | Operational missions. Four new possible bases. |
| III | 2 & 4 | 2004 & 2005 | 14 & 40 | 6 | Lunar Base 1 | IOC/NOC-1 | 5 Crew members on surface, 1 in LLO |
| III | 6 & 7 | 2006 | 90 | 12 | Lunar Base 1 | NOC-2 | |
| III | All piloted flts from 9 on. | 2007 - 2020 | 365 | 18 | Lunar Base1 | NOC-3/-4 | 3 Crew members assigned to observe Mars Dress rehearsal in 2009 |
| III | 19 | 2009 | 30 | 6 | Nearby Lunar Base 1 | NOC-4 | 6 Crew members at nearby base for Mars dress rehearsal |
| IV | 2 | 2004 | 14 | 6 | Landing Site 1 | IOC | 5 Crew members on surface, 1 in LLO |
| IV | 4 | 2006 | 45 | 6 | Lunar Base 1 | NOC-1 | |
| IV | 6 | 2008 | 90 | 6 | Lunar Base 1 | NOC-1 | |
| IV | 9 | 2010 | 180 | 6 | Lunar Base 1 | NOC-1 | |
| IV | 11 | 2011 | 40 | 6 | Nearby Lunar Base 1 | NOC-2 | 6 Crew members at nearby base for Mars dress rehearsal |
| IV | 12 | 2011 | 90 | 6 | Lunar Base 1 | NOC-2 | 3 Crew members assigned to observe Mars Dress rehearsal |
| IV | 14 - 18 | 2013 - 2017 | - | 6 | - | NOC-2 | Optional missions |

# Mars Mission Parameters

| Architecture | Flight No(s) | Dates | Stay Time (Days) | Crew Size | Base/Site | Ops Phase | Remarks |
|---|---|---|---|---|---|---|---|
| I | 2 | 2014 | 30-100 | 6 | MB 1 | IOC | |
| I | | | | | | | |
| I | 4 | 2016 | 600 | 6 | MB 2 | NOC | |
| I | | | | | | | |
| I | 6 | 2018 | - | 6 | - | - | Optional Mission |
| I | | | | | | | |
| I | 8 | 2020 | - | 6 | - | - | Optional Mission |
| II | 2 | 2014 | 30-100 | 6 | MB 1 | IOC | |
| II | | | | | | | |
| II | 4 | 2016 | 600 | 6 | MB 2 | NOC-1 | |
| II | | | | | | | |
| II | 6 | 2018 | 600 | 6 | MB 3 | NOC-1 | |
| II | | | | | | | |
| II | 8 | 2020 | 600 | 6 | MB 4 | NOC-2 | Permanent Base |
| III | 2 | 2014 | 30-100 | 6 | MB 1 | IOC-1 | |
| III | | | | | | | |
| III | 4 | 2016 | 600 | 6 | MB 2 | NOC | |
| III | | | | | | | |
| III | 6 | 2018 | - | 6 | - | - | Optional Mission |
| III | | | | | | | |
| III | 8 | 2020 | - | 6 | - | - | Optional Mission |
| III | | | | | | | |
| IV | 2 | 2016 | 30-100 | 6 | MB 1 | IOC | |
| IV | | | | | | | |
| IV | 4 | 2018 | 600 | 6 | MB 1 | NOC | |
| IV | | | | | | | |
| IV | 6 | 2020 | - | 6 | - | - | Optional Mission |
| IV | | | | | | | |

# Synthesis Group Report

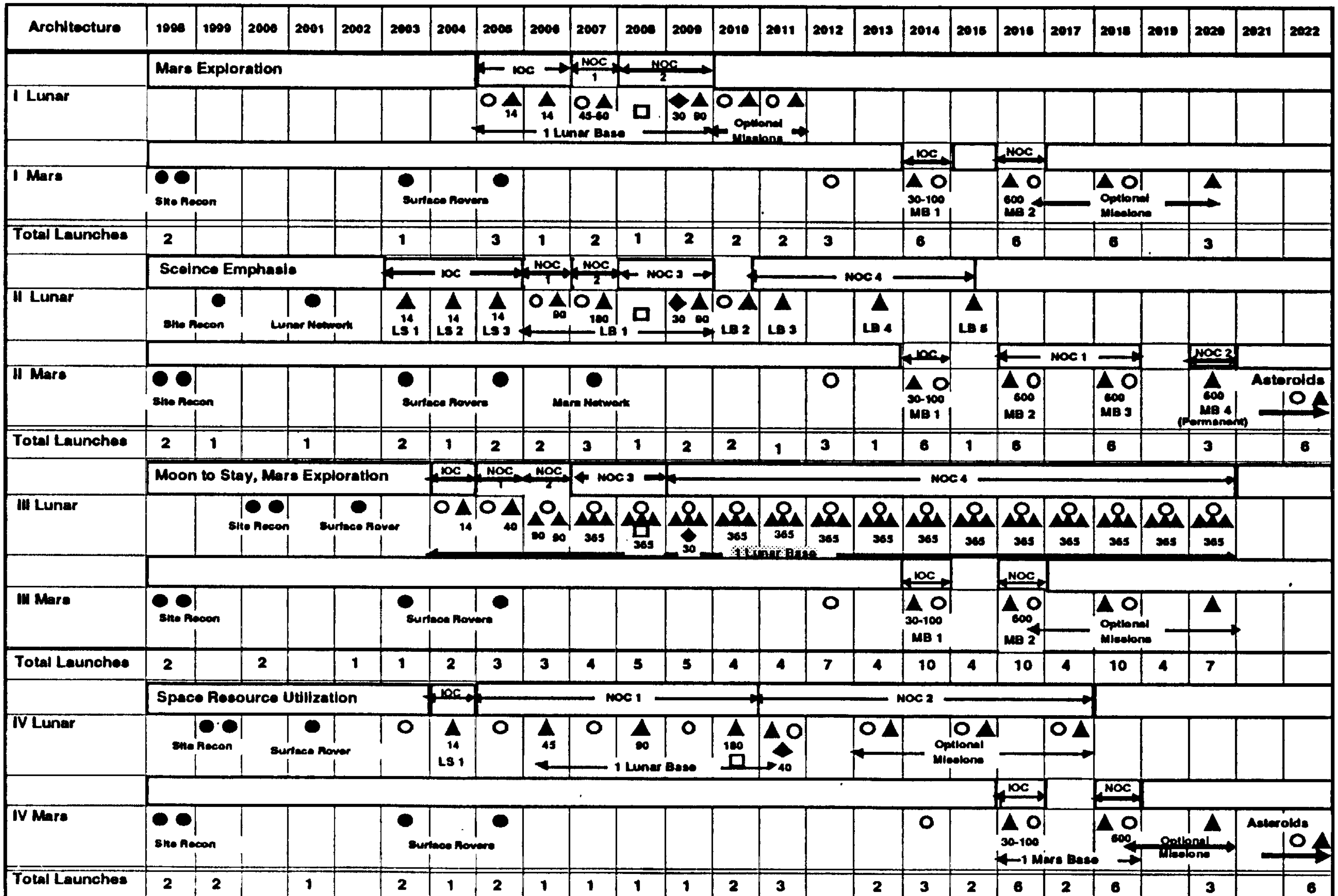
# Lunar/Mars Mission

# Manifest

# Architectures I thru IV

## Stafford Report Lunar/Mars Mission Manifests Architectures I, II, III & IV

Updated 10 Sept 1991




**Note:**
All Mars cargo and piloted missions and asteroids cargo and piloted missions require 3 earth-to-LEO HLLV (250 - 300 tonne) launches.

**Legend:**
- ● Mission Precursor
- ○ Cargo Mission
- ▲ Piloted Mission
- □ Mars Dress Rehearsal (Cargo)
- ◆ Mars Dress Rehearsal (Piloted. Located nearby lunar base)

LS = Landing Site
LB = Lunar Base
MB = Mars Base

# Cargo Manifest

## Architectures I, II, III & IV

# ARCHITECTURE I MARS EXPLORATION MANIFEST

| Year | Payloads to be Processed and Launched |
| --- | --- |
| 1998 | Two Mars Orbiters - Site Reconnaissance (Assumed 15 to 30 days launch date separation like back-to-back Viking and Voyager missions based on planetary launch constraints) |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Habitat<br>- Electrical Power Supply<br>- Cryo-tank Test Set<br>- Unloader<br>- Consumables<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Unpressurized Rover<br>- Solar Flare Detector<br>- Consumables |
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Scientific Instruments |
| 2007 | One Lunar Cargo Lander<br>- Pressurized Rover<br>- Nuclear Power Plant<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2008 | One Lunar Cargo Lander - (Mars Dress Rehearsal)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |
| 2009 | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Crew) |

## ARCHITECTURE I MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2009 | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Assistance/Observer Crew) |
| 2010 | One Lunar Cargo Lander - Optional mission for Mars equipment redesign checkout if required.<br><br>One Lunar Piloted Vehicle - Optional mission for Mars equipment redesign checkout if required. |
| 2011 | One Lunar Cargo Lander - Optional mission for Mars equipment redesign checkout if required.<br><br>One Lunar Piloted Vehicle - Optional mission for Mars equipment redesign checkout if required. |
| 2012 | One Mars Cargo Lander (for 2014 manned mission)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables<br><br>One Mars Cargo Lander (for 2016 manned mission)<br>- (Same as 2012 Cargo Lander plus emergency Earth return propellant and crew excursion vehicle) |
| 2016 | One Mars Piloted Vehicle<br>- (Same as 2014 Piloted Vehicle plus ISRU Demo Unit)<br><br>One Mars Cargo Lander - Optional Mission<br>- (For optional 2018 manned mission. Same as 2012 Cargo Lander) |
| 2018 | One Mars Piloted Vehicle - Optional Mission<br><br>One Mars Cargo Lander - Optional Mission<br>- (For optional 2020 manned mission. Same as 2012 Cargo Lander) |
| 2020 | One Mars Piloted Vehicle - Optional Mission<br>- (Same as 2014 Piloted Vehicle) |

ARCHITECTURE II SCIENCE EMPHASIS MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance<br>(Back-to-back missions assumed) |
| 1999 | One Lunar Orbiter - Site Reconnaissance<br>(Launch date can be shifted in 1999 to accommodate Mars planetary window in 1998) |
| 2001 | One Lunar Surface Network Transporter<br>- Eight Geophysical/Environmental stations each with its own descent stage |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Pressurized Rover<br>- Telerobotic Prospector<br>- Consumables<br>- Solar Flare Detector<br>- Environmental Condition Package<br>- Test Telescope<br>- Magnetospheric Observer |
| 2004 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander (Same as 2003 mission) |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander (Same as 2003 mission) |
| 2006 | One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Power Plant<br>- Habitat Waste Management System<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Telerobotic Prospector<br>- ISRU Experiment<br>- Low Energy Cosmic Ray Detector<br>- Four Element VLF Array<br>- Transit Telescope |

ARCHITECTURE II SCIENCE EMPHASIS MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2007 | One Mars Surface Network Transporter<br>- Eight Geophysical/Environmental stations each with its own descent stage<br>- Eight Meteorological Stations |
| | One Lunar Cargo Lander<br>- Pressurized Rover (improved)<br>- Telescope (4 meter)<br>- Interferometer<br>- Radio Telescope<br>- New Life Support System |
| | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- ISRU Experiment<br>- Robot (for Pressurized Rover)<br>- Consumables |
| 2008 | One Lunar Cargo Lander - (Mars Dress Rehearsal)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |
| 2009 | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Crew) |
| | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Assistance/Observer Crew) |
| 2010 | One Lunar Cargo Lander Operational Mission |
| | One Lunar Piloted Vehicle Operational Mission |
| 2011 | One Lunar Piloted Vehicle Operational Mission |
| 2012 | One Mars Cargo Lander (for 2014 manned mission)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |

ARCHITECTURE II SCIENCE EMPHASIS MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2013 | One Lunar Piloted Vehicle - Operational Mission |
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables |
| | One Mars Cargo Lander (for 2016 manned mission)<br>- (Same as 2012 Cargo Lander plus emergency Earth return propellant and crew excursion vehicle) |
| 2015 | One Lunar Piloted Vehicle - Operational Mission |
| 2016 | One Mars Piloted Vehicle<br>- (Same as 2014 Piloted Vehicle plus ISRU Demo Unit) |
| | One Mars Cargo Lander - Operational Mission<br>- (For optional 2018 manned mission. Same as 2012 Cargo Lander) |
| 2018 | One Mars Piloted Vehicle - Operational Mission |
| | One Mars Cargo Lander - Operational Mission<br>- (For operational 2020 manned mission. Same as 2012 Cargo Lander)<br>- ISRU ($H_2$, $O_2$, $H_2O$ and $CH_4$) |
| 2020 | One Mars Piloted Vehicle - Operational Mission<br>- (Same as 2014 Piloted Vehicle) |
| 2020+ | One Asteroid Cargo Vehicle<br>- Robotic Precursor |
| | One Asteroid Piloted Vehicle<br>- Manned Maneuvering Units<br>- Surface Scientific Instruments<br>- ISRU Experiment<br>- Consumables |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance<br>(Back-to-back missions assumed) |
| 2000 | Two Lunar Orbiters - Site Reconnaissance<br>(Launches can be separated by 30 days or more) |
| 2002 | One Lunar Surface Rover<br>- Communication Orbiter<br>- Descent Stage<br>- Subsurface Radar Imager |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2004 | One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Power Plant<br>- Unloader<br>- Bulldozer #1<br>- Cryo-tank Test Set<br>- Scientific Instruments<br>- Optical Telescope (Test)<br>- Pressurized Rover #1<br>- Solar Flare Detector |
| | One Lunar Piloted Vehicle<br>- Orbiter<br>- Descent Stage<br>- Unpressurized Rover<br>- Consumables |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| | One Lunar Cargo Lander<br>- Pressurized Rover #2<br>- Consumables<br>- Transit Telescope<br>- Four Meter Telescope |
| | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- ISRU Gas Demonstrator<br>- Scientific Instruments |
| 2006 | One Lunar Cargo Lander<br>- Habitat (Add-on to first Habitat)<br>- Volatile Production Plant |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Unpressurized Rover #2<br>- Resource Laboratory<br>- Waste Recycle Demonstrator<br>- Optical Inferferometer |
| | One Lunar Piloted Vehicle (Launched within 7 days of the first Piloted Vehicle)<br>- Orbiter<br>- Lander<br>- Consumables<br>- Food Production Equipment |
| 2007 | One Lunar Cargo Lander<br>- Habitat (Add-on to first two Habitats)<br>- Consumables |
| | Three Lunar Piloted Vehicles (Launched in the first, second and third quarters, building an outpost for 18 crew members)<br>- Orbiter<br>- Lander |
| 2008 | One Lunar Cargo Lander<br>- Bulldozer #2<br>- Consumables<br>- Four Meter Telescope Expansion Kit |
| | Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| | One Lunar Cargo Lander- (Mars Dress Rehearsal)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |
| 2009 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST (continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2009 | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Crew) |
| 2010 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| 2011 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| 2012 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander<br><br>One Mars Cargo Lander (for 2014 manned mission)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |
| 2013 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| 2014 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables<br><br>One Mars Cargo Lander (for 2016 manned mission)<br>- (Same as 2012 Cargo Lander plus emergency Earth return propellant and crew excursion vehicle) |
| 2015 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| 2016 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander<br><br>One Mars Piloted Vehicle.<br>- (Same as 2014 manned mission)<br><br>One Mars Cargo Lander - Optional Mission<br>- (For optional 2018 Mars manned mission. Same as 2012 Cargo Lander) |
| 2017 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| 2018 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander<br><br>One Mars Piloted Vehicle - Optional Mission<br><br>One Mars Cargo Lander - Optional Mission<br>- (For optional 2020 manned mission. Same as 2012 Cargo Lander) |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2019 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander |
| 2020 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters)<br>- Orbiter<br>- Lander<br><br>One Mars Piloted Vehicle - Optional Mission<br>- (Same as 2014 Piloted Vehicle) |

ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance<br>(Back-to-back launches assumed) |
| 1999 | Two Lunar Orbiters - Site Reconnaissance<br>(Launches can be separated by 30 days or more, and shifted further into 1999 to accommodate the Mars Reconnaissance Orbiter planetary window in 1998) |
| 2001 | One Lunar Surface Rover<br>- Communication Orbiter<br>- Descent Stage |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- ISRU Experimental Plant |
| 2004 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Descent Stage<br>- Unpressurized Rover<br>- Consumables |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Power Plant<br>- ISRU Production Plant |
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2007 | One Lunar Cargo Lander<br>- Pressurized Rover<br>- ISRU Expansion Kit<br>- Construction Equipment & Tools |
| 2008 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2009 | One Lunar Cargo Lander<br>- Beam Power Experiment<br>- Scientific Instruments |

ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2010 | One Lunar Cargo Lander - (Mars Dress Rehearsal)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment |
| | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2011 | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Crew) |
| | One Lunar Piloted Vehicle - (Mars Dress Rehearsal Assistance/Observer Crew) |
| | One Lunar Cargo Lander |
| 2013 | One Lunar Cargo Lander - Optional Mission |
| | One Lunar Piloted Vehicle - Optional Mission |
| 2014 | One Mars Cargo Lander (for 2016 manned mission)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Power Plant<br>- Unloader/Mover<br>- Consumables<br>- Scientific Instruments<br>- Communication Equipment<br>- ISRU Atmoshere Reduction Plant |
| 2015 | One Lunar Cargo Lander - Optional Mission |
| | One Lunar Piloted Vehicle - Optional Mission |
| 2016 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables |
| | One Mars Cargo Lander (for 2018 manned mission)<br>- (Same as 2014 Cargo Lander plus emergency Earth return propellant and crew excursion vehicle)<br>- ISRU Expansion<br>- Greenhouse Food Production |

ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2017 | One Lunar Cargo Lander - Optional Mission |
| | One Lunar Piloted Vehicle - Optional Mission |
| 2018 | One Mars Piloted Vehicle<br>- (Same as 2016 Mars manned mission) |
| | One Mars Cargo Lander - Optional Mission<br>- (For optional 2020 manned mission. Same as 2014 Cargo Lander) |
| 2020 | One Mars Piloted Vehicle - Optional Mission |
| 2020+ | One Asteroid Cargo Vehicle<br>- Robotic Precursor |
| | One Asteroid Piloted Vehicle<br>- Manned Maneuvering Units<br>- Surface Scientific Instruments<br>- ISRU Experiment<br>- Consumables |

# Appendix B

# Quick-look Assessment

# of the

# Synthesis Group Report,

# its

# Architectures and their Impacts

# on KSC Launch and Landing Operations

# Appendix B

This appendix contains the results of a quick-look assessment of the Synthesis Group Report conducted by a joint NASA and MDSSC KSC LTFOS team to determine the impact of implementing the recommendations of the Synthesis Group on KSC launch facilities and operations. The data was documented in a presentation format as requested by Kennedy Space Center Technology and Advanced Projects Office. An early version of the assessment, in a narrative style, with launch manifests (derived from the report) for each architecture is included in this appendix as backup material.

# General Observations

- The missions will require new launch pads and payload processing facilities which must accommodate payloads up to 250 metric tons. Some of the foreseeable increases in payload handling capabilities and new capabilities include:
  - Helium 3 handling
  - Nuclear thermal propulsion processing
  - EVA suit refurbishment and repair
  - Increased cryo storage and handling
  - Education and outreach programs
  - Expanded crew quartering and training
  - Aerobrake assembly, checkout, and refurbishment
  - Expanded battery processing needs
  - Large scale sterilization
  - Advanced materials assembly, modification, and repair
  - High data rate system, test and checkout, storage, and retrieval
  - Expert system neural net test and checkouts

# General Observations (continued)

- ❑ The method KSC uses to process the Shuttle and payloads will have to be evaluated, and where appropriate, new ground operational techniques developed to handle the increase of processing flows more efficiently, i.e., scheduling techniques, process automation, etc,.

# Impacts of an SEI Program Office

- Requiring a separate SEI Program office (similar to the SSF office would require:
  - Unique Staff
  - Support from other KSC directorates on an as-needed basis
  - Duplication of other KSC directorate functions
- Recommend identifying the specific functions that such an office would be expected to perform to avoid duplication of local effort and responsibility

# Payload late Access Capability

- Although the report does not address late access capabilities for payload servicing and monitoring, it is probable that late access will be required at the pad.
- Payload processing assessments should make provisions to provide this capability

# Launch Rate Impacts

- The MSFC Launch/On-orbit Processing Study, 1989 indicates that existing and currently planned KSC payload facilities will not be sufficient for processing payloads. A minimum of four new payload processing facilities were identified, including a large payload integration facility and facilities for processing of individual SEI elements.

- Lack of suitable payload processing facilities will be a constraint to meeting SEI mission objectives.

# Impact of R&D Test Flights

- The schedules shown for each of the architectures include only operational flights. Additional flights will be required to support research and development efforts which will add to the amount of payload processing that will be required at KSC.

- Additional R&D flights, flight demonstrations, and other test objectives (EASE-ACCESS flights for Station for example) will add to the amount of payload processing.

# Synchronous Relay Satellite Processing Impact

- The schedules do not indicate the processing and the launch of Mars synchronous relay satellites. However, the figure on page 94 indicates that there is a relay satellite network. It is highly probable that such a communication system will be used and these satellites will be processed and launched as payloads.
- The processing of these satellites will increase the amount of payload processing requirements to support the SEI program.

# Impacts of Ka Band Communication Requirements

- ❑ Ka Band communications are baselined for all Mars architectures. KSC capabilities to process Ka Band data and relay it to other sites (JSC, JPL) in support of payload test and checkouts will be required.
- ❑ Supporting payloads using Ka Band communications will require additional communication support at KSC

# Logistics Impacts

- ❑ Lunar and Mars missions will result in equipment, vehicles, and facilities, being carried to and left on extraterrestrial surfaces with the intent of returning to and reusing them during long term surface operations.
- ❑ An integrated logistics support system and infrastructure capable of tracking planetary surface and space vehicle support requirements will be required to retain these systems in an operational state.

# Impact of Helium Downloading

- Architecture IV envisions the downloading to Earth of two metric tons of Helium 3 annually.
- This may require capabilities which are beyond the normal KSC payload offloading and safing capabilities already in existence.

# Nuclear Power Impacts

- ❑ Nuclear power has been baselined for all Mars surface power and nuclear thermal rocket propulsion Mars transfer vehicles.
- ❑ Current KSC RTG facilities are insufficient for processing and storing the Mars nuclear reactor payloads. A new KSC nuclear reactor processing facility is required.

# Impact of Propellant Management

- ❑ The large amounts of propellants which are to be used will require either large storage and tanking areas or local production. If other program launches are to be continued, enough propellant may be required to justify local production.
- ❑ This should become the subject of an assessment to determine anticipated requirements.

# Robotics Impacts

- Robotics and telepresence are mentioned in numerous places in the document.
- Extensive use of robotics will require a test and checkout capability.

# Life Sciences Impacts

- An increased reliance on life support systems (especially closed systems) will place a greater emphasis on the KSC CELSS projects.
- If humans and associated biological systems are to be sent on long duration flight, extended quarantine periods will be required.
- Large quarantine facilities and sterilization capabilities will be required for the processing of large payloads and the associated life support systems

# Payload Complexities

- Each architecture will be comprised of many different launch elements (payloads)
  - The payloads will employ a wide range of technologies and support requirements
- For any given architecture, each launch will be comprised of different payloads
  - Each payload will have unique payload processing requirements
- The varying nature of a diverse set of payloads complicates the payload processing far more than the repetitive nature of the launch vehicles
- A more diverse set of support requirements and unique state-of-the-art technical activities must be addressed than have been considered on past and current programs

Attachment 1

# Backup Material

# for

# Appendix B

# Quick-look Assessment

# of the

# Synthesis Group Report

KSC Impacts
as Noted from Review of the

Report of the Synthesis Group
on
America's Space Exploration Initiative

ASSUMPTIONS:

Throughout the SEI time period, the Shuttle, or its replacement, will continue to launch the typical class of payloads it has these past ten years and to resupply the Space Station.

The launch rate will fully utilize the existing boosters and payload facilities.

The launch manifests (as derived from the report) for each of the architectures are attached.

GENERAL OBSERVATIONS:

The missions will require new launch pads and payload processing facilities which must accommodate payloads up to 250 metric tons. High technology payloads technologies will require unique support. Some of the foreseeable increases in payload handling capabilities and new capabilities include:

- Helium 3 handling
- Nuclear thermal propulsion processing
- EVA suit refurbishment and repair
- Increased cryo storage and handling
- Education and outreach programs
- Expanded crew quartering and training
- Aerobrake assembly, checkout, and refurbishment
- Expanded battery processing needs
- Large scale sterilization
- Advanced materials assembly, modification, repair
- High data rate systems, test and checkout, storage, and retrieval
- Expert system neural net test and checkouts

The method KSC uses to process the Shuttle and payloads will have to be evaluated, and where appropriate, new ground operational techniques developed to handle the increase of processing flows more efficiently and effectively i.e., scheduling techniques, process automation, etc.

IMPACTS:

Program Office
Requiring a separate SEI office (similar to the SS Office) would require:

- Unique Staff
- Support from other KSC directorates on an as-needed basis
- Duplication of other KSC directorate functions such as facilities, payloads and communications groups

General Launch Site Capabilities
Although the report does not address late access capabilities for payload servicing and monitoring, it is probable that late access will be required at the pad. Payload processing assessments should make provisions to provide this capability.

Launch Rate
All of the SEI architectures utilize lunar and martian transfer vehicles, landers, and extraterrestrial elements such as habitats. Previous studies (MSFC Launch/On-Orbit Processing Study, 1989) assessed existing and currently planned KSC payload facilities for suitability and availability to support SEI launch rate. A minimum of four new payload processing facilities were identified, including a large payload integration facility and facilities for processing of individual SEI elements. Reference p 96, column 1, paragraph 4.

It appears that the schedules shown for each of the architectures will include only operational flights. Additional flights will be required to support research and developments efforts which will add to the amount of payload processing that will be required at KSC, be it either on the Shuttle or on other vehicles. For example, the SEI program will probably require a flight assessment of the nuclear propulsion system which will add to the amount of payload processing resources required at KSC to support the program.

The schedules also do not indic ate the processing and the launching of Mars synchronous relay satellites. However, the figure on page 94 indicates that there is a relay satellite network. It is highly probable that such a communication system will be used and these satellites will be processed and launched as payloads.

The initial architectures discuss the requirements for precursor flights as early as 1998 to 2005. The time between these flights and the landing of men and/or cargo can be as long as 14 years. (Reference Architecture I). It is probable that other precursor flights will be needed in the intervening years. The schedule does not reflect that additional data gathering flights might make a greater impact on the payload processing capability than is being considered at this time.

Communications

Ka Band communications are baselined for all Mars architectures. KSC capabilities to process Ka Band data and relay it to other sites (JSC, JPL) in support of payload test and checkouts will be required. Reference p 81, column 1, paragraph 2.

Logistics

Architecture IV envisions the downloading to Earth of two metric tons of Helium-3 annually. This may require capabilities which are beyond the normal KSC payload offloading and safing capabilities already in existence. Reference page A-35, column 2, paragraph 3.

Lunar and Mars missions will result in equipment, vehicles, and facilities, being carried to and left on extraterrestrial surfaces with the intent of returning to and reusing them during long term surface operations. An integrated logistics support system and infrastructure capable of tracking planetary surface and space vehicle support requirements will be required to retain these systems in and operational state.

Nuclear Power

Nuclear power has been baselined for all Mars surface power and nuclear thermal rocket propulsion Mars transfer vehicles. Current KSC RTG facilities are insufficient for processing and storing the Mars nuclear reactor payloads. A new KSC nuclear reactor processing facility is required. Reference p 67, column 2, paragraph 1 and p 71, column 2, paragraph 4.

Propellant Management

The large amounts of propellants which are to be used will require either large storage and tanking areas or local production. If other program launches are to continue, enough propellant may be required to justify local production. This should become the subject of an assessment to determine anticipated requirements.

Robotics

Robotics and telepresence are mentioned in numerous places in the document. There must be a capability to test and checkout the equipment.

Life Sciences

An increased reliance on life support systems (especially if the system is to be closed) will place a greater emphasis on KSC CELSS projects. KSC is a leader in closed chamber plant studies and is the NASA lead center for plant space biology.

Other considerations should be given to the preparations for closed loop systems. If humans, and associated biological systems are to be sent on a long duration flight, extended quarantine periods will be required. The magnitude of supporting this quarantine will require additional KSC involvement. Pages 5 and 6.

Payload Complexities

The payloads will be comprised of several different launch elements, and require a wide range of technologies and support requirements. The varying nature of the payloads makes them more complicated than the repetitive launch vehicle preparations. Therefore, a far more diverse set of support requirements and unique state-of-the-art technical needs must be addressed for the payload processing activities than considered in the past and for launch vehicles.

ARCHITECTURE I MARS EXPLORATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - site reconnaissance (assumed 15 to 30 days launch date separation like back-to-back Viking and Voyager missions based on planetary launch constraints.) |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| | One Lunar Cargo Lander<br>- Habitat<br>- Electrical Power Supply<br>- Cryo-tank Verification Test Set<br>- Consumables<br>- Unloader |
| | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Consumables<br>- Unpressurized Rover<br>- Solar Flare Detector |
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2007 | One Lunar Cargo Lander<br>- Pressurized Rover<br>- Nuclear Electrical Power Plant |
| | One Lunar Piloted Vehicle |
| 2008 | One Lunar Cargo Lander - (Mars Dress Rehearsal)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Electrical Power Plant<br>- Unloader/Rover<br>- Consumables<br>- Scientific Exploration Instruments<br>- Communication Equipment |
| 2009 | One Lunar Piloted Vehicle (Mars Dress Rehearsal Crew) |
| | One Lunar Piloted Vehicle (Mars Dress Rehearsal Assistance/Observer Crew) |

ARCHITECTURE I MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2010 | One Lunar Cargo Lander (Potential) |
| | One Lunar Piloted Vehicle (Potential) |
| 2011 | One Lunar Cargo Lander (Potential) |
| | One Lunar Piloted Vehicle(Potential) |
| 2012 | One Mars Cargo Lander<br>- Habitat<br>- Electrical Power Supply (nuclear with solar cell backup)<br>- Unloader/Mover<br>- Unloader/Mover<br>- Pressurized Rover<br>- Consumables<br>- Communication Equipment<br>- Scientific Exploration Equipment |
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables |
| | One Mars Cargo Lander (for 2016 mission)<br>- (Same as 2012 Cargo Lander plus MEV propellant) |
| 2016 | One Mars Piloted Vehicle<br>- (Same as 2014 Piloted Vehicle) |
| | One Mars Cargo Lander (for 2018 mission) (Potential)<br>- (Same as 2012 Cargo Lander) |
| 2018 | One Mars Piloted Vehicle (for 2020 mission) (Potential) |
| | One Mars Cargo Lander - Optional Mission<br>- (Same as 2012 Cargo Lander) |
| 2020 | One Mars Piloted Vehicle (Potential)<br>- (Same as 2014 Piloted Vehicle) |

ARCHITECTURE II SCIENCE EMPHASIS MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance<br>(Back-to-back missions assumed) |
| 1999 | One Lunar Orbiter<br>(Launch date can be shifted in 1999 to accommodate Mars planetary window in 1998) |
| 2001 | One Lunar Surface Network Transporter<br>- Eight Geophysical/Environmental stations each with its own descent stage |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>  - Pressurized Rover<br>  - Telerobotic Prospector<br>  - Consumables<br>  - Solar Flare Detector<br>  - Environmental Condition Package<br>  - Test Telescope<br>  - Magnetospheric Observer |
| 2004 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander (Same as 2003 mission) |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander (Same as 2003 mission) |
| 2006 | One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Electrical Power Supply<br>- ISRU Experiment<br>- Habitat Waste Management System<br>- Robotic Prospector<br><br>One Lunar Piloted Vehicle<br>- Transit Telescope<br>- Low Energy Cosmic Ray Detector<br>- VLF Four Element Array<br>- Consumables |

## ARCHITECTURE II SCIENCE EMPHASIS MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2007 | One Mars Surface Network Transporter<br>- Eight Geophysical/Environmental stations each with its own descent stage<br>- Eight Meteorological Stations |
| | One Lunar Cargo Lander<br>- Pressurized Rover (improved)<br>- Telescope (4 meter)<br>- Interferometer<br>- Radio Telescope<br>- New Life Support System |
| | One Lunar Piloted Vehicle<br>- Robot (for Pressurized Rover)<br>- Waste Management System<br>- ISRU (to produce food and breathable gas)<br>- Consumables |
| 2008 | One Lunar Cargo Lander<br>- (Mars Dress Rehearsal) |
| 2009 | One Lunar Piloted Vehicle<br>- (Mars Dress Rehearsal Crew) |
| | One Lunar Piloted Vehicle<br>- (Mars Dress Rehearsal Assistance/Observer Crew) |
| 2010 | One Lunar Cargo Lander |
| | One Lunar Piloted Vehicle |
| 2011 | One Lunar Piloted Vehicle |
| 2012 | One Mars Cargo Lander |
| 2013 | One Lunar Piloted Vehicle |
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables |
| | One Mars Cargo Lander (for 2016 mission) |
| 2015 | One Lunar Piloted Vehicle |
| 2016 | One Mars Cargo Lander |
| | One Mars Piloted Vehicle |

ARCHITECTURE II SCIENCE EMPHASIS MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
| --- | --- |
| 2018 | One Mars Cargo Lander (permanent base)<br>- Habitats<br>- ISRU (H3, O2, H2O, CH4)<br>- Electrical Power Supply<br>- Unloader/Mover<br>- Pressurized Rover<br>- Communication Equipment |
| 2020 | One Mars Piloted Vehicle (permanent base)<br>- Transfer/orbit Vehicle<br>- Lander<br>- Crew Return Vehicle<br>- Consumables<br>- Scientific Exploration Equipment |
| 2020+ | One Asteroid Robotic Vehicle<br><br>One Asteroid Piloted Vehicle<br>- Manned Maneuvering Units<br>- Surface Scientific Packages<br>- ISRU Experiment<br>- Consumables<br>- ISRU |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance (back-to-back launches assumed) |
| 2000 | Two Lunar Reconnaissance Orbiters (launches can be separated by 30 days or more) |
| 2002 | One Lunar Surface Rover<br>- Descent Stage<br>- Subsurface Radar Imager |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2004 | One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Electrical Power Plant<br>- Unloader<br>- Bulldozer<br>- Cryo-tank Verification Test Set<br>- Scientific Instruments<br>- Optical Telescope (Test)<br>- Pressurized Rover #1<br>- Solar Flare Detector<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Descent Stage<br>  - Unpressurized Rover<br>  - Consumables |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Pressurized Rover #2<br>- Consumables<br>- Transit Telescope<br>- Four Meter Telescope<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>  - ISRU Gas Demonstrator<br>  - Scientific Instruments |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2006 | 2006 One Lunar Cargo Lander<br>- Additional Habitat<br>- ISRU Volatile Products Plant<br><br>One Lunar Piloted Vehicle<br>- Unpressurized Rover<br>- Resource Laboratory<br>- Waste Recycle Demonstrator<br>- Optical Interferometer<br><br>One Lunar Piloted Vehicle<br>(Launched within 7 days of the first Piloted Vehicle)<br>- Consumables<br>- Food Production Equipment |
| 2007 | One Lunar Cargo Lander<br>- Additional Habitat<br>- Consumables<br><br>Three Lunar Piloted Vehicles |
| 2008 | One Lunar Cargo Lander<br>- Bulldozer<br>- Consumables<br>- Four Meter Telescope Expansion Kit<br><br>Three Lunar Piloted Vehicles<br><br>One Lunar Cargo Lander- (Mars Dress Rehearsal) |
| 2009 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles<br><br>One Lunar Piloted Vehicle (Mars Dress Rehearsal Crew) |
| 2010 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles (Launched in the first, second and third quarters) |
| 2011 | One Lunar Cargo Lander<br><br>Three Lunar Piloted Vehicles |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST

(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2012 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Cargo Lander (for 2014 mission) |
| 2013 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| 2014 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Cargo Lander (for 2016 manned mission) |
| | One Mars Piloted Vehicle |
| 2015 | Repeats 2013 Lunar Missions |
| 2016 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Piloted Vehicle |
| | One Mars Cargo Lander (2018 mission) (Optional) |
| 2017 | Repeats 2013 Lunar Missions |
| 2018 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Piloted Vehicle |
| | One Mars Cargo Lander (2020 mission) (Optional) |
| 2019 | Repeats 2013 Lunar Missions |
| 2020 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Piloted Vehicle (Optional) |

## ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance (back-to-back launches assumed) |
| 1999 | Two Lunar Reconnaissance Orbiters (launches can be separated by 30 days or more, and shifted further into 1999 to accommodate the Mars Reconnaissance Orbiter planetary window in 1998) |
| 2001 | One Lunar Surface Rover<br>- Descent Stage |
| 2003 | One Lunar Cargo Lander<br>- ISRU gas extraction (experimental)<br><br>One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2004 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Descent Stage<br>  - Consumables<br>  - Unpressurized Rover |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Habitat<br>- Electrical Power System<br>- ISRU Production Plant |
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2007 | One Lunar Cargo Lander<br>- Rover<br>- ISRU Expansion Kit<br>- Site Construction Equipment<br>- Tools |
| 2008 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2009 | One Lunar Cargo Lander<br>- Beam Power Experiment<br>- Scientific Instruments |

## ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2010 | One Lunar Cargo Lander<br>(Mars Dress Rehearsal) |
| | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2011 | One Lunar Piloted Vehicle<br>- Consumables |
| | One Lunar Piloted Vehicle<br>(Mars Dress Rehearsal Crew)<br>- Consumables |
| | One Lunar Cargo Lander (Potential) |
| 2013 | One Lunar Cargo Lander (Potential) |
| | One Lunar Piloted Vehicle (Potential) |
| 2014 | One Mars Cargo Lander (2016 mission)<br>- Same as Architecture I<br>- ISRU Atmosphere Reproduction Plant |
| 2015 | One Lunar Cargo Lander (Potential) |
| | One Lunar Piloted Vehicle (Potential) |
| 2016 | One Mars Cargo Lander (2018 mission)<br>- Same as Architecture I<br>- ISRU Expansion<br>- Greenhouse Food Production |
| | One Mars Piloted Vehicle<br>- Same as Architecture I |
| 2017 | One Lunar Cargo Lander (Potential) |
| | One Lunar Piloted Vehicle (Potential) |
| 2018 | One Mars Piloted Vehicle<br>- Same as Architecture I |
| | One Mars Cargo Lander (2020 mission) (Potential) |
| 2020 | One Mars Piloted Vehicle (Potential) |
| 2020+ | One Asteroid Cargo Vehicle<br>- Robotic Vehicle<br>- Piloted Vehicle |

# Appendix B

# Quick-look Assessment

# of the

# Synthesis Group Report,

# its

# Architectures and their Impacts

# on KSC Launch and Landing Operations

# Appendix B

This appendix contains the results of a quick-look assessment of the Synthesis Group Report conducted by a joint NASA and MDSSC KSC LTFOS team to determine the impact of implementing the recommendations of the Synthesis Group on KSC launch facilities and operations. The data was documented in a presentation format as requested by Kennedy Space Center Technology and Advanced Projects Office. An early version of the assessment, in a narrative style, with launch manifests (derived from the report) for each architecture is included in this appendix as backup material.

# General Observations

- The missions will require new launch pads and payload processing facilities which must accommodate payloads up to 250 metric tons. Some of the foreseeable increases in payload handling capabilities and new capabilities include:
  - Helium 3 handling
  - Nuclear thermal propulsion processing
  - EVA suit refurbishment and repair
  - Increased cryo storage and handling
  - Education and outreach programs
  - Expanded crew quartering and training
  - Aerobrake assembly, checkout, and refurbishment
  - Expanded battery processing needs
  - Large scale sterilization
  - Advanced materials assembly, modification, and repair
  - High data rate system, test and checkout, storage, and retrieval
  - Expert system neural net test and checkouts

# General Observations
# (continued)

- ❑ The method KSC uses to process the Shuttle and payloads will have to be evaluated, and where appropriate, new ground operational techniques developed to handle the increase of processing flows more efficiently, i.e., scheduling techniques, process automation, etc,.

# Impacts of an SEI Program Office

- ❑ Requiring a separate SEI Program office (similar to the SSF office would require:
  - Unique Staff
  - Support from other KSC directorates on an as-needed basis
  - Duplication of other KSC directorate functions
- ❑ Recommend identifying the specific functions that such an office would be expected to perform to avoid duplication of local effort and responsibility

# Payload late Access Capability

- ❑ Although the report does not address late access capabilities for payload servicing and monitoring, it is probable that late access will be required at the pad.
- ❑ Payload processing assessments should make provisions to provide this capability

# Launch Rate Impacts

- The MSFC Launch/On-orbit Processing Study, 1989 indicates that existing and currently planned KSC payload facilities will not be sufficient for processing payloads. A minimum of four new payload processing facilities were identified, including a large payload integration facility and facilities for processing of individual SEI elements.
- Lack of suitable payload processing facilities will be a constraint to meeting SEI mission objectives.

# Impact of R&D Test Flights

- ❑ The schedules shown for each of the architectures include only operational flights. Additional flights will be required to support research and development efforts which will add to the amount of payload processing that will be required at KSC.
- ❑ Additional R&D flights, flight demonstrations, and other test objectives (EASE-ACCESS flights for Station for example) will add to the amount of payload processing.

# Synchronous Relay Satellite Processing Impact

- The schedules do not indicate the processing and the launch of Mars synchronous relay satellites. However, the figure on page 94 indicates that there is a relay satellite network. It is highly probable that such a communication system will be used and these satellites will be processed and launched as payloads.
- The processing of these satellites will increase the amount of payload processing requirements to support the SEI program.

# Impacts of Ka Band Communication Requirements

- ❑ Ka Band communications are baselined for all Mars architectures. KSC capabilities to process Ka Band data and relay it to other sites (JSC, JPL) in support of payload test and checkouts will be required.
- ❑ Supporting payloads using Ka Band communications will require additional communication support at KSC

# Logistics Impacts

- ❑ Lunar and Mars missions will result in equipment, vehicles, and facilities, being carried to and left on extraterrestrial surfaces with the intent of returning to and reusing them during long term surface operations.
- ❑ An integrated logistics support system and infrastructure capable of tracking planetary surface and space vehicle support requirements will be required to retain these systems in an operational state.

# Impact of Helium Downloading

- Architecture IV envisions the downloading to Earth of two metric tons of Helium 3 annually.
- This may require capabilities which are beyond the normal KSC payload offloading and safing capabilities already in existence.

# Nuclear Power Impacts

- Nuclear power has been baselined for all Mars surface power and nuclear thermal rocket propulsion Mars transfer vehicles.
- Current KSC RTG facilities are insufficient for processing and storing the Mars nuclear reactor payloads.  A new KSC nuclear reactor processing facility is required.

# Impact of Propellant Management

- The large amounts of propellants which are to be used will require either large storage and tanking areas or local production. If other program launches are to be continued, enough propellant may be required to justify local production.
- This should become the subject of an assessment to determine anticipated requirements.

# Robotics Impacts

- Robotics and telepresence are mentioned in numerous places in the document.
- Extensive use of robotics will require a test and checkout capability.

# Life Sciences Impacts

- An increased reliance on life support systems (especially closed systems) will place a greater emphasis on the KSC CELSS projects.
- If humans and associated biological systems are to be sent on long duration flight, extended quarantine periods will be required.
- Large quarantine facilities and sterilization capabilities will be required for the processing of large payloads and the associated life support systems

# Payload Complexities

- ❑ Each architecture will be comprised of many different launch elements (payloads)
  - The payloads will employ a wide range of technologies and support requirements
- ❑ For any given architecture, each launch will be comprised of different payloads
  - Each payload will have unique payload processing requirements
- ❑ The varying nature of a diverse set of payloads complicates the payload processing far more than the repetitive nature of the launch vehicles
- ❑ A more diverse set of support requirements and unique state-of-the-art technical activities must be addressed than have been considered on past and current programs

Attachment 1

# Backup Material

# for

# Appendix B

# Quick-look Assessment

# of the

# Synthesis Group Report

KSC Impacts
as Noted from Review of the

Report of the Synthesis Group
on
America's Space Exploration Initiative

ASSUMPTIONS:

Throughout the SEI time period, the Shuttle, or its replacement, will continue to launch the typical class of payloads it has these past ten years and to resupply the Space Station.

The launch rate will fully utilize the existing boosters and payload facilities.

The launch manifests (as derived from the report) for each of the architectures are attached.

GENERAL OBSERVATIONS:

The missions will require new launch pads and payload processing facilities which must accommodate payloads up to 250 metric tons. High technology payloads technologies will require unique support. Some of the foreseeable increases in payload handling capabilities and new capabilities include:

- Helium 3 handling
- Nuclear thermal propulsion processing
- EVA suit refurbishment and repair
- Increased cryo storage and handling
- Education and outreach programs
- Expanded crew quartering and training
- Aerobrake assembly, checkout, and refurbishment
- Expanded battery processing needs
- Large scale sterilization
- Advanced materials assembly, modification, repair
- High data rate systems, test and checkout, storage, and retrieval
- Expert system neural net test and checkouts

The method KSC uses to process the Shuttle and payloads will have to be evaluated, and where appropriate, new ground operational techniques developed to handle the increase of processing flows more efficiently and effectively i.e., scheduling techniques, process automation, etc.

IMPACTS:

Program Office
Requiring a separate SEI office (similar to the SS Office) would require:

- Unique Staff
- Support from other KSC directorates on an as-needed basis
- Duplication of other KSC directorate functions such as facilities, payloads and communications groups

General Launch Site Capabilities
Although the report does not address late access capabilities for payload servicing and monitoring, it is probable that late access will be required at the pad. Payload processing assessments should make provisions to provide this capability.

Launch Rate
All of the SEI architectures utilize lunar and martian transfer vehicles, landers, and extraterrestrial elements such as habitats. Previous studies (MSFC Launch/On-Orbit Processing Study, 1989) assessed existing and currently planned KSC payload facilities for suitability and availability to support SEI launch rate. A minimum of four new payload processing facilities were identified, including a large payload integration facility and facilities for processing of individual SEI elements. Reference p 96, column 1, paragraph 4.

It appears that the schedules shown for each of the architectures will include only operational flights. Additional flights will be required to support research and developments efforts which will add to the amount of payload processing that will be required at KSC, be it either on the Shuttle or on other vehicles. For example, the SEI program will probably require a flight assessment of the nuclear propulsion system which will add to the amount of payload processing resources required at KSC to support the program.

The schedules also do not indic ate the processing and the launching of Mars synchronous relay satellites. However, the figure on page 94 indicates that there is a relay satellite network. It is highly probable that such a communication system will be used and these satellites will be processed and launched as payloads.

The initial architectures discuss the requirements for precursor flights as early as 1998 to 2005. The time between these flights and the landing of men and/or cargo can be as long as 14 years. (Reference Architecture I). It is probable that other precursor flights will be needed in the intervening years. The schedule does not reflect that additional data gathering flights might make a greater impact on the payload processing capability than is being considered at this time.

Communications

Ka Band communications are baselined for all Mars architectures. KSC capabilities to process Ka Band data and relay it to other sites (JSC, JPL) in support of payload test and checkouts will be required. Reference p 81, column 1, paragraph 2.

Logistics

Architecture IV envisions the downloading to Earth of two metric tons of Helium-3 annually. This may require capabilities which are beyond the normal KSC payload offloading and safing capabilities already in existence. Reference page A-35, column 2, paragraph 3.

Lunar and Mars missions will result in equipment, vehicles, and facilities, being carried to and left on extraterrestrial surfaces with the intent of returning to and reusing them during long term surface operations. An integrated logistics support system and infrastructure capable of tracking planetary surface and space vehicle support requirements will be required to retain these systems in and operational state.

Nuclear Power

Nuclear power has been baselined for all Mars surface power and nuclear thermal rocket propulsion Mars transfer vehicles. Current KSC RTG facilities are insufficient for processing and storing the Mars nuclear reactor payloads. A new KSC nuclear reactor processing facility is required. Reference p 67, column 2, paragraph 1 and p 71, column 2, paragraph 4.

Propellant Management

The large amounts of propellants which are to be used will require either large storage and tanking areas or local production. If other program launches are to continue, enough propellant may be required to justify local production. This should become the subject of an assessment to determine anticipated requirements.

Robotics

Robotics and telepresence are mentioned in numerous places in the document. There must be a capability to test and checkout the equipment.

Life Sciences

An increased reliance on life support systems (especially if the system is to be closed) will place a greater emphasis on KSC CELSS projects. KSC is a leader in closed chamber plant studies and is the NASA lead center for plant space biology.

Other considerations should be given to the preparations for closed loop systems. If humans, and associated biological systems are to be sent on a long duration flight, extended quarantine periods will be required. The magnitude of supporting this quarantine will require additional KSC involvement. Pages 5 and 6.

Payload Complexities

The payloads will be comprised of several different launch elements, and require a wide range of technologies and support requirements. The varying nature of the payloads makes them more complicated than the repetitive launch vehicle preparations. Therefore, a far more diverse set of support requirements and unique state-of-the-art technical needs must be addressed for the payload processing activities than considered in the past and for launch vehicles.

ARCHITECTURE I MARS EXPLORATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - site reconnaissance (assumed 15 to 30 days launch date separation like back-to-back Viking and Voyager missions based on planetary launch constraints.) |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Habitat<br>- Electrical Power Supply<br>- Cryo-tank Verification Test Set<br>- Consumables<br>- Unloader<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>- Consumables<br>- Unpressurized Rover<br>- Solar Flare Detector |
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2007 | One Lunar Cargo Lander<br>- Pressurized Rover<br>- Nuclear Electrical Power Plant<br><br>One Lunar Piloted Vehicle |
| 2008 | One Lunar Cargo Lander - (Mars Dress Rehearsal)<br>- Habitat<br>- Pressurized Rover<br>- Nuclear Electrical Power Plant<br>- Unloader/Rover<br>- Consumables<br>- Scientific Exploration Instruments<br>- Communication Equipment |
| 2009 | One Lunar Piloted Vehicle (Mars Dress Rehearsal Crew)<br><br>One Lunar Piloted Vehicle (Mars Dress Rehearsal Assistance/Observer Crew) |

ARCHITECTURE I MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2010 | One Lunar Cargo Lander (Potential)<br><br>One Lunar Piloted Vehicle (Potential) |
| 2011 | One Lunar Cargo Lander (Potential)<br><br>One Lunar Piloted Vehicle(Potential) |
| 2012 | One Mars Cargo Lander<br>- Habitat<br>- Electrical Power Supply (nuclear with solar cell backup)<br>- Unloader/Mover<br>- Unloader/Mover<br>- Pressurized Rover<br>- Consumables<br>- Communication Equipment<br>- Scientific Exploration Equipment |
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables<br><br>One Mars Cargo Lander (for 2016 mission)<br>- (Same as 2012 Cargo Lander plus MEV propellant) |
| 2016 | One Mars Piloted Vehicle<br>- (Same as 2014 Piloted Vehicle)<br><br>One Mars Cargo Lander (for 2018 mission) (Potential)<br>- (Same as 2012 Cargo Lander) |
| 2018 | One Mars Piloted Vehicle (for 2020 mission) (Potential)<br><br>One Mars Cargo Lander - Optional Mission<br>- (Same as 2012 Cargo Lander) |
| 2020 | One Mars Piloted Vehicle (Potential)<br>- (Same as 2014 Piloted Vehicle) |

## ARCHITECTURE II SCIENCE EMPHASIS MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance<br>(Back-to-back missions assumed) |
| 1999 | One Lunar Orbiter<br>(Launch date can be shifted in 1999 to accommodate Mars planetary window in 1998) |
| 2001 | One Lunar Surface Network Transporter<br>- Eight Geophysical/Environmental stations each with its own descent stage |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>  - Pressurized Rover<br>  - Telerobotic Prospector<br>  - Consumables<br>  - Solar Flare Detector<br>  - Environmental Condition Package<br>  - Test Telescope<br>  - Magnetospheric Observer |
| 2004 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander (Same as 2003 mission) |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander (Same as 2003 mission) |
| 2006 | One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Electrical Power Supply<br>- ISRU Experiment<br>- Habitat Waste Management System<br>- Robotic Prospector<br><br>One Lunar Piloted Vehicle<br>- Transit Telescope<br>- Low Energy Cosmic Ray Detector<br>- VLF Four Element Array<br>- Consumables |

ARCHITECTURE II SCIENCE EMPHASIS MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2007 | One Mars Surface Network Transporter<br>- Eight Geophysical/Environmental stations each with its own descent stage<br>- Eight Meteorological Stations |
| | One Lunar Cargo Lander<br>- Pressurized Rover (improved)<br>- Telescope (4 meter)<br>- Interferometer<br>- Radio Telescope<br>- New Life Support System |
| | One Lunar Piloted Vehicle<br>- Robot (for Pressurized Rover)<br>- Waste Management System<br>- ISRU (to produce food and breathable gas)<br>- Consumables |
| 2008 | One Lunar Cargo Lander<br>- (Mars Dress Rehearsal) |
| 2009 | One Lunar Piloted Vehicle<br>- (Mars Dress Rehearsal Crew) |
| | One Lunar Piloted Vehicle<br>- (Mars Dress Rehearsal Assistance/Observer Crew) |
| 2010 | One Lunar Cargo Lander |
| | One Lunar Piloted Vehicle |
| 2011 | One Lunar Piloted Vehicle |
| 2012 | One Mars Cargo Lander |
| 2013 | One Lunar Piloted Vehicle |
| 2014 | One Mars Piloted Vehicle<br>- Transfer/Orbiter Vehicle<br>- Lander<br>- Crew Earth Return Vehicle<br>- Consumables |
| | One Mars Cargo Lander (for 2016 mission) |
| 2015 | One Lunar Piloted Vehicle |
| 2016 | One Mars Cargo Lander |
| | One Mars Piloted Vehicle |

## ARCHITECTURE II SCIENCE EMPHASIS MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2018 | One Mars Cargo Lander (permanent base)<br>- Habitats<br>- ISRU (H3, O2, H2O, CH4)<br>- Electrical Power Supply<br>- Unloader/Mover<br>- Pressurized Rover<br>- Communication Equipment |
| 2020 | One Mars Piloted Vehicle (permanent base)<br>- Transfer/orbit Vehicle<br>- Lander<br>- Crew Return Vehicle<br>- Consumables<br>- Scientific Exploration Equipment |
| 2020+ | One Asteroid Robotic Vehicle<br><br>One Asteroid Piloted Vehicle<br>- Manned Maneuvering Units<br>- Surface Scientific Packages<br>- ISRU Experiment<br>- Consumables<br>- ISRU |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance (back-to-back launches assumed) |
| 2000 | Two Lunar Reconnaissance Orbiters (launches can be separated by 30 days or more) |
| 2002 | One Lunar Surface Rover<br>- Descent Stage<br>- Subsurface Radar Imager |
| 2003 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2004 | One Lunar Cargo Lander<br>- Habitat<br>- Nuclear Electrical Power Plant<br>- Unloader<br>- Bulldozer<br>- Cryo-tank Verification Test Set<br>- Scientific Instruments<br>- Optical Telescope (Test)<br>- Pressurized Rover #1<br>- Solar Flare Detector<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Descent Stage<br>  - Unpressurized Rover<br>  - Consumables |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Pressurized Rover #2<br>- Consumables<br>- Transit Telescope<br>- Four Meter Telescope<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander<br>  - ISRU Gas Demonstrator<br>  - Scientific Instruments |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2006 | 2006 One Lunar Cargo Lander<br>- Additional Habitat<br>- ISRU Volatile Products Plant |
| | One Lunar Piloted Vehicle<br>- Unpressurized Rover<br>- Resource Laboratory<br>- Waste Recycle Demonstrator<br>- Optical Interferometer |
| | One Lunar Piloted Vehicle<br>(Launched within 7 days of the first Piloted Vehicle)<br>- Consumables<br>- Food Production Equipment |
| 2007 | One Lunar Cargo Lander<br>- Additional Habitat<br>- Consumables |
| | Three Lunar Piloted Vehicles |
| 2008 | One Lunar Cargo Lander<br>- Bulldozer<br>- Consumables<br>- Four Meter Telescope Expansion Kit |
| | Three Lunar Piloted Vehicles |
| | One Lunar Cargo Lander- (Mars Dress Rehearsal) |
| 2009 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Lunar Piloted Vehicle (Mars Dress Rehearsal Crew) |
| 2010 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles (Launched in the first, second and third quarters) |
| 2011 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |

ARCHITECTURE III MOON TO STAY & MARS EXPLORATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2012 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Cargo Lander (for 2014 mission) |
| 2013 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| 2014 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Cargo Lander (for 2016 manned mission) |
| | One Mars Piloted Vehicle |
| 2015 | Repeats 2013 Lunar Missions |
| 2016 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Piloted Vehicle |
| | One Mars Cargo Lander (2018 mission) (Optional) |
| 2017 | Repeats 2013 Lunar Missions |
| 2018 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Piloted Vehicle |
| | One Mars Cargo Lander (2020 mission) (Optional) |
| 2019 | Repeats 2013 Lunar Missions |
| 2020 | One Lunar Cargo Lander |
| | Three Lunar Piloted Vehicles |
| | One Mars Piloted Vehicle (Optional) |

ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST

| Year | Payloads to be Processed and Launched |
|---|---|
| 1998 | Two Mars Orbiters - Site Reconnaissance (back-to-back launches assumed) |
| 1999 | Two Lunar Reconnaissance Orbiters (launches can be separated by 30 days or more, and shifted further into 1999 to accommodate the Mars Reconnaissance Orbiter planetary window in 1998) |
| 2001 | One Lunar Surface Rover<br>- Descent Stage |
| 2003 | One Lunar Cargo Lander<br>- ISRU gas extraction (experimental)<br><br>One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage |
| 2004 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Descent Stage<br>  - Consumables<br>  - Unpressurized Rover |
| 2005 | One Mars Surface Rover<br>- Communications Orbiter<br>- Descent Stage<br><br>One Lunar Cargo Lander<br>- Habitat<br>- Electrical Power System<br>- ISRU Production Plant |
| 2006 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2007 | One Lunar Cargo Lander<br>- Rover<br>- ISRU Expansion Kit<br>- Site Construction Equipment<br>- Tools |
| 2008 | One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2009 | One Lunar Cargo Lander<br>- Beam Power Experiment<br>- Scientific Instruments |

ARCHITECTURE IV SPACE RESOURCE UTILIZATION MANIFEST
(continued)

| Year | Payloads to be Processed and Launched |
|---|---|
| 2010 | One Lunar Cargo Lander<br>(Mars Dress Rehearsal)<br><br>One Lunar Piloted Vehicle<br>- Orbiter<br>- Lander |
| 2011 | One Lunar Piloted Vehicle<br>- Consumables<br><br>One Lunar Piloted Vehicle<br>(Mars Dress Rehearsal Crew)<br>- Consumables<br><br>One Lunar Cargo Lander (Potential) |
| 2013 | One Lunar Cargo Lander (Potential)<br><br>One Lunar Piloted Vehicle (Potential) |
| 2014 | One Mars Cargo Lander (2016 mission)<br>- Same as Architecture I<br>- ISRU Atmosphere Reproduction Plant |
| 2015 | One Lunar Cargo Lander (Potential)<br><br>One Lunar Piloted Vehicle (Potential) |
| 2016 | One Mars Cargo Lander (2018 mission)<br>- Same as Architecture I<br>- ISRU Expansion<br>- Greenhouse Food Production<br><br>One Mars Piloted Vehicle<br>- Same as Architecture I |
| 2017 | One Lunar Cargo Lander (Potential)<br><br>One Lunar Piloted Vehicle (Potential) |
| 2018 | One Mars Piloted Vehicle<br>- Same as Architecture I<br><br>One Mars Cargo Lander (2020 mission) (Potential) |
| 2020 | One Mars Piloted Vehicle (Potential) |
| 2020+ | One Asteroid Cargo Vehicle<br>- Robotic Vehicle<br>- Piloted Vehicle |

# Appendix C

# White Paper

# on

# Comparison of the Functional Testing

# of the

# RL-10 Liquid Rocket Engine

# and the

# Space Shuttle Main Engine (SSME)

# Appendix C

Appendix C is a white paper on the comparison of the functional testing of the RL-10 and Space Shuttle Main Engine. The comparison was undertaken to provide insight regarding common test requirements that would be applicable to Lunar and Mars Excursion Vehicles (LEV and MEV).

# White Paper
# on
# Comparison of the Functional Testing of the RL10 Liquid Rocket Engine and the Space Shuttle Main Engine (SSME)

**11 September 1991**

prepared for

**Office of Advanced Systems and Technology**
**NASA Kennedy Space Center**

prepared by

**McDonnell Douglas Space Systems Company**
**Kennedy Space Center**

**NASA Contract Number: NAS10-11567**

Approved by:

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MDSSC-LTFOS Study Manager

J. R. Reiss
NASA CP-FGO
Study Manager

## Table of Contents

# Comparison of the Functional Testing of the RL10 Liquid Rocket Engine and the Space Shuttle Main Engine (SSME)

## 1.0 Purpose

One element common to all of the Lunar Excursion Vehicle or Mars Excursion Vehicle (LEV/MEV) concepts developed to date during the Space Exploration Initiative (SEI) transportation studies was the use of multiple cryogenic propellant (LOX/LH2) engines, with a combined thrust level in the range of 60,000 to 80,000 pounds. Advanced models of the RL10 type were the engines of choice. The primary purpose of this paper is to emphasize the fact that a great deal of prelaunch activity, related to space vehicle testing and particularly engine checks, is currently accomplished on this planet at the launch site prior to the launch countdown.

The RL10 Liquid Rocket Engine has been operational since 1962 and is currently used on the Centaur vehicle. Centaur prelaunch testing is complex. One hundred and four tests are performed on Centaur alone. Many of these tests are related to the RL10 engines. In addition, functional tests are performed on the engine at the manufacturer's plant, prior to installation in the Centaur and again at the launch site. These tests require the use of special purpose ground support equipment, a team of engineers, and skilled technicians. All tests are considered necessary to assure successful launch from this planet and it would be reasonable to assume that some similar type of testing will be required for the LEV/MEV prior to descent from low lunar orbit (LLO), or low Martian orbit (LMO), and prior to lift-off from another planetary surface.

The purpose of performing LEV/MEV preflight checks is to provide confidence that the vehicle systems and subsystems will function properly, and to detect malfunctions that would present a safety hazard. For the reusable vehicles the data obtained over a series of tests could be assessed for trends that may signal an impending failure. Due to the limited resources available to conduct preflight checks in space or on a planetary surface, the LEV/MEV will require a high degree of automation, with embedded sensors, to provide a built-in-test/built-in-test-equipment (BIT/BITE) capability. The current RL10 engine design has essentially no built-in-test capability.

The Space Shuttle Main Engine (SSME) is the only other operational rocket engine currently in the NASA inventory which uses LOX/LH2 as the propellant. The SSME is an advanced design engine with a limited built-in-test capability. Although the RL10 and the SSME are based on completely different designs, comparing the functional tests performed on these engines provides insight regarding common test requirements that would be applicable to the LEV/MEV.

## 2.0 Engine Descriptions

To provide a frame of reference the following paragraphs briefly describe the RL10 and the SSME.

### 2.1 RL10 DESCRIPTION

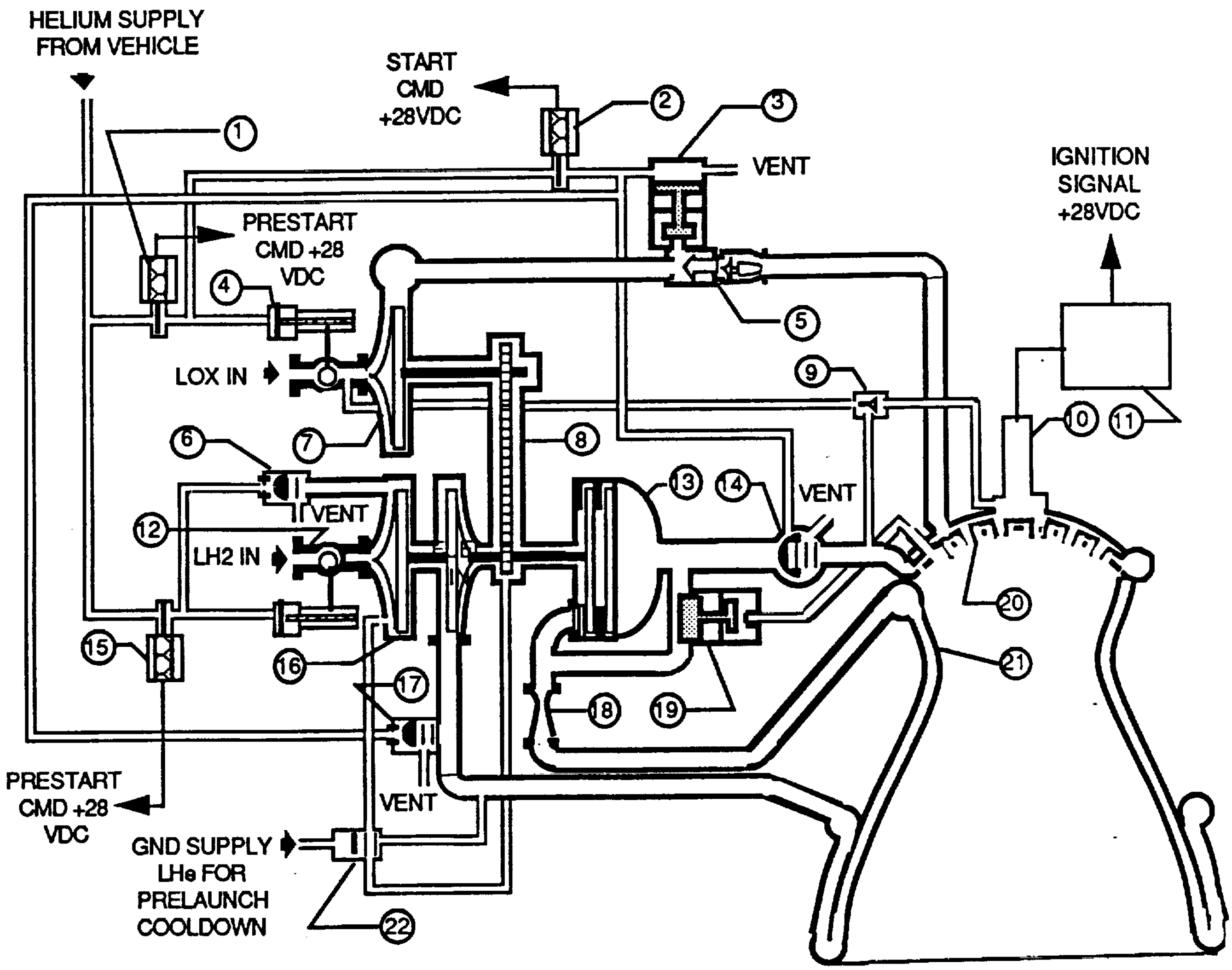
The RL10 rocket engine is a regeneratively cooled, expansion cycle turbopump fed engine with a single combustion chamber (see figure 2.1-1). The RL10A-3-3A produces a rated thrust of 16,500 pounds in a space vacuum. The RL10A-4 model with a 20 inch nozzle extension produces a rated vacuum thrust of 20,800 pounds. Liquid oxygen and liquid hydrogen at a normal mixture ratio of 5.5:1 are used as propellants. Gaseous helium is used to actuate valves for starting and stopping the engine. Electrically actuated solenoid valves control the flow of gaseous helium to the engine valves and electrical signals actuate the ignition system.

The typical first burn start sequence is initiated by a prelaunch cooldown with cold helium (obtained by vaporization of ground supplied liquid helium), flowing through the fuel turbopump and overboard through fuel cooldown vents. The oxidizer pump is cooled by conduction from the fuel system. Cooldown is required to ensure that fuel and oxidizer remain in the liquid state as they flow from the propellant tanks to the pump inlets. If gaseous fuel or oxidizer appeared at the either of the pump inlets, the pump(s) would cavitate and the engine would fail to start.

Cooldown for subsequent firings in space is initiated by fuel and oxidizer prestart signals which open the prestart solenoid valves. The prestart solenoid valves in turn open the the fuel and oxidizer inlet valves allowing a controlled leakage of onboard propellants (fuel and oxidizer) to flow through the system and out of the combustion chamber. Also, the oxidizer prestart signal allows oxidizer to flow through the internal by-pass passages of the oxidizer flow control valve to the injector.

At engine start the main fuel shut-off valve opens, fuel cooldown valves close and oxidizer flow control by-pass closes. The electrical igniter is energized simutaneously with the start signal for A-3-3A engines and at

+0.320 seconds for A-4 engines. When the main fuel valve opens fuel flows through the thrust chamber cooling tubes where it absorbs residual heat and changes to gaseous hydrogen. The gaseous hydrogen passes through the venturi and into the turbine causing the turbine to rotate, which in turn drives the fuel and oxidizer turbopumps. Fuel from the




1. Oxidizer Prestart Solenoid Valve
2. Start Solenoid Valve
3. Oxidizer Cooldown Valve
4. Oxidizer Inlet Shut-off Valve
5. Oxidizer Flow Control Valve
6. Fuel Pump Interstage Cooldown Valve
7. Oxidizer Turbopump
8. Drive Gear
9. Igniter Oxidizer Supply Valve
10. Igniter
11. Ignition Case
12. Fuel Inlet Shut-off Valve
13. Turbine
14. Main Fuel Shut-off Valve
15. Fuel Prestart Solenoid Valve
16. Fuel Turbopump
17. Fuel Pump Discharge Cooldown Valve
18. Venturi
19. Thrust Control Valve
20. Injector
21. Thrust Chamber Cooling Jacket
22. Prelaunch Cooldown Check Valve

Figure 2.1-1: Principal Elements of the RL10A-4 Rocket Engine turbine flows through the fuel shut-off valve and into the propellant injector. The electrical spark ignites a mixture of hydrogen and oxygen that is ported through the center of the injector. Main chamber ignition occurs as soon as a combustible mixture is available in the combustion chamber. During the start transient, increasing oxidizer pump pressure opens the oxidizer flow control inlet valve permitting full oxidizer flow into the injector and closes the igniter oxidizer supply valve shutting off the oxidizer flow to the igniter.

Constant engine thrust during steady state operation is obtained by regulating combustion chamber pressure to a predetermined value. Deviation in combustion chamber pressure causes the thrust control valve to increase or decrease the area of the variable turbine bypass port. Increases or decreases in bypass area vary the fuel flow through the turbine, which in turn increases or decreases chamber pressure. A relatively simple redesign of the thrust control system could provide the variable thrust required by the LEV/MEV.

## 2.2 SSME DESCRIPTION

The SSME is a pre-burner type engine rated at 470,000 pounds thrust in vacuum or 375,000 pounds at sea level (see figure 2.2-1). Liquid oxygen and liquid hydrogen at a normal mixture ratio of 6:1 are used as propellants. The engine is throttleable from 305,000 pounds (65%) to 512,000 pounds (109%) in 4,700-pound increments.

The identifying feature of a preburner engine is that most of the fuel and a small amount of oxidizer are "preburned" in a preburner at an extremely fuel-rich mixture ratio. The resulting fuel-rich exhaust gas is used to power the turbopump turbine, and is then injected into the main combustion chamber along with the remaining oxidizer and coolant fuel, all to be "final-burned". Two low pressure turbopumps (oxidizer and fuel) serve as boost pumps for the high pressure fuel and oxidizer turbopumps. This arrangement permits lower ullage pressures in the propellant tank and higher pump speeds.

Throttling of the SSME is accomplished by varying the output of the preburners, thus varying the speed of the high pressure turbopumps and, therefore, the propellant mass flow rates. In order to start, the SSME needs only the propellant tank head pressure for initial propellant flow and spark igniter to initiate combustion. It has an electronic controller to perform all checkout, start run, monitoring, and shutdown functions. Propellant valves are hydraulically driven with a pneumatic backup for shutdown. A recirculation system allows liquid hydrogen to flow through the fuel system and returns the gaseous hydrogen to the fuel tank, thus cooling the fuel system and providing a pressurant for the fuel tank. The

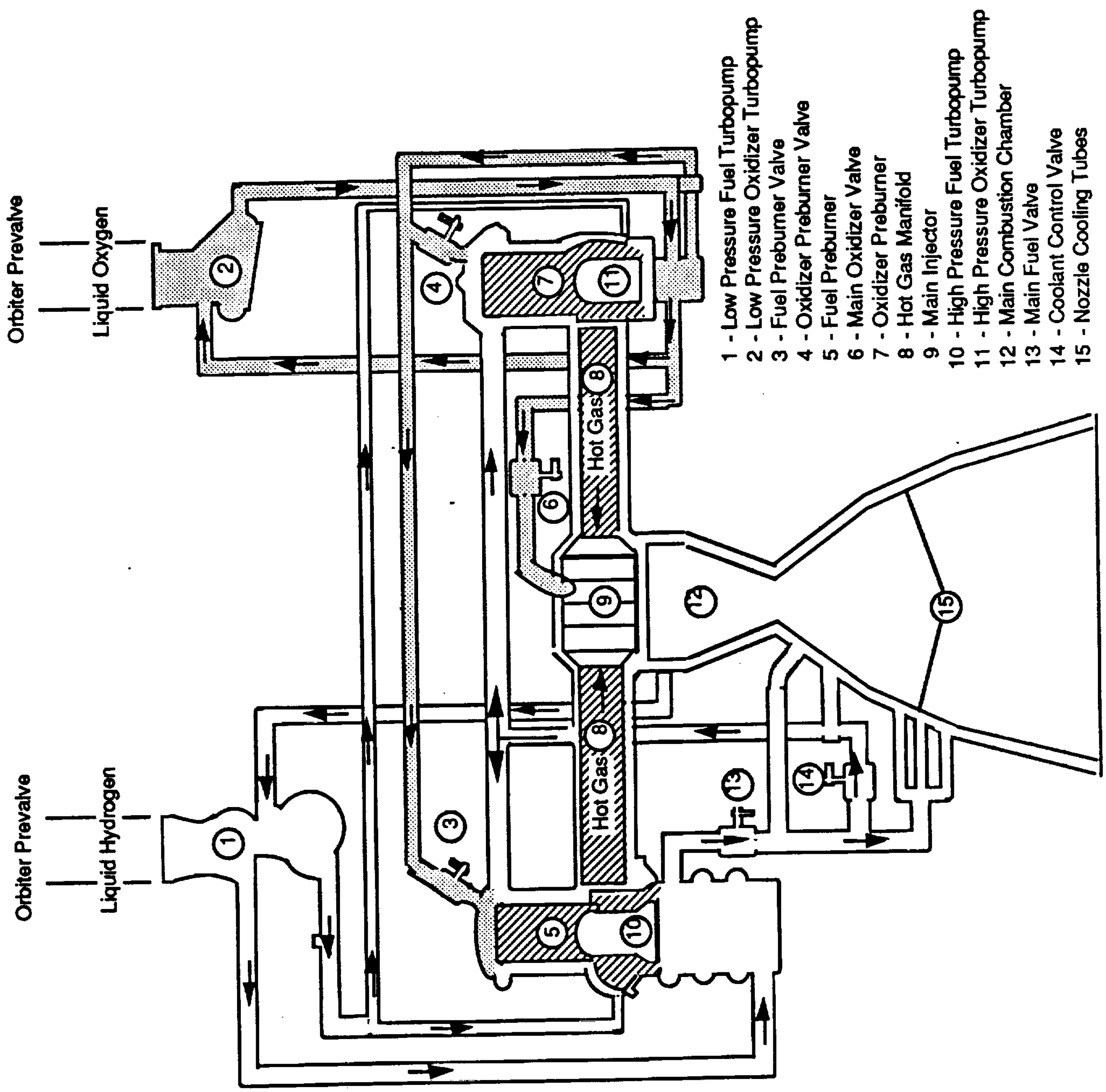



Figure 2.2-1: Principal Elements of the Shuttle Main Engine

oxidizer system is cooled by allowing liquid to flow through the system and vent to the atmosphere as a gas.

## 3.0 Functional Tests

The functional tests described in the RL10 Service Manual were used as the baseline for this comparison between the RL10 and the SSME. Due to the different design philosophies employed for each engine, an exact correlation of components and tests was not possible; however, similar components and similar tests were compared (See Attachment 1) to provide a general indication of the testing that will require special attention in the design of the LEV/MEV.

Common types of functional tests preformed on the RL10 and the SSME can be grouped into five broad categories as follows:

- Torque checks
- Electrical checks
- Valve actuation checks
- Internal leakage checks
- External leakage checks.

There are other tests and checks performed on both engines, such as internal and external inspections and borescope inspections. However, for the purpose of this analysis only functional tests, which are related to prelaunch operations, were compared.

### 3.1 Torque Checks

Breakaway and running torque checks of the RL10 and SSME turbopumps are performed in the same manner by manually rotating the turbopumps with a torque wrench and measuring the torque through several revolutions.

On the RL10, the turbopump torque check is made at the accessory drive shaft and a cover plate must be removed to gain access to the shaft. A torque check is also performed on the RL10 gear driven oxidizer flow control valve. A cover plate must also be removed to gain access to the drive shaft. A torque check of the inlet adapter of the prelaunch cooldown check valve is performed and the liquid helium inlet line must be loosened prior to the check.

On the SSME the High Pressure Oxidizer Turbopump (HPOTP), High Pressure Fuel Turbopump (HPFTP), Low Pressure Oxidizer Turbopump (LPOTP) and Low Pressure Fuel Turbopump (LPFTP) torque checks are made at the drive shafts and cover plates must be removed to gain access to the shafts. Shaft travel is also measured at this time and compared to previous measurements to ensure travel is within limits.

## 3.2 Electrical Checks

Four tests are performed on the RL10 electrical system during functional testing. The first is an electrical system check which is a series of insulation resistance measurements with a megohmmeter between connector pins within a connector, and from connector pins in a connector to the connector shell. Also, included are continuity checks of solenoids, sensors and transducers. The second test is an electrical bonding check where the resistance measurements are made between the connector shells and the mounting brackets. These tests are conducted at the manufacturer's plant and generally not repeated at the launch site.

The third electrical test is a check of the operation of the ignition system using ground power and a voltmeter to measure the output voltage at an indicator/monitor circuit, a visual observation of the spark for at least 10 seconds, and resistance checks.

The igniter system for the RL10 is an old vacuum tube design and the box containing the circuitry must be pressurized to prevent arcing at high altitudes. The fourth electrical test is actually a check of the pressurization of the ignition exciter box by measuring its deflection. Checks are performed immediately prior to shipment of the vehicle to the launch site, prior to engine installation on the vehicle, and every 30 days at the launch site. A final check is made not more than one day prior to launch.

Electrical tests performed on the SSME are automated and provide a calibration of the sensors, a checkout of igniters, and a checkout of redundancy circuits. This is performed prior to orbiter rollout from the OPF. Although the actual test is automated using the computerized Launch Processing System (LPS), test equipment set-up requires approximately eight hours to complete.

## 3.3 Valve Actuation Checks

For the RL10, valve actuation checks are performed on the following:

Prestart and Start Solenoid Valves
Fuel and Oxidizer Inlet Shutoff Valve
Fuel Pump Cooldown Valves (Interstage and Discharge)
Main Fuel Shutoff Valve
Oxidizer Flow Control Bypass Valve

Actuation of the prestart and start solenoid valves is accomplished using ground power and a ground helium supply. Energizing the prestart and start solenoids will actuate the fuel and oxidizer inlet valves, the fuel pump cooldown valves, the main fuel shutoff valve and the oxidizer flow control valve. Actuation is verified audibly and by feeling the valve housing.

The SSME valves are hydraulically operated. Actuation checks are performed on the following SSME valves:

Main Fuel Valve (MFV)
Main Oxidizer Valve (MOV)
Fuel Preburner Oxidizer Valve (FPOV)
Oxidizer Preburner Oxidizer Valve (OPOV)
Chamber Coolant Valve (CCV)

Actuation of the valves is accomplished under computer control and built-in position sensors are read by the computer to verify proper cycling and timing.

### 3.4 Internal Leak Checks

Internal leak checks are those checks which measure leakage past valve seats and seals.

Pressure and leak tests of the RL10 valves is generally accomplished with ground supplied GN2 in the liquid oxygen system, or GHe in the liquid hydrogen system, a pressure gage and a flow meter. Protective covers and/or a desiccants generally must be removed to connect the GN2, or GHe, lines and flow meters. In many cases the flow rate though the valve is measured at a fitting on a throat plug installed in the engine thrust chamber. In several checks the flow is measured at a vent tube or purge connector. In all cases the valves are checked individually and connections are made manually.

Internal leak checks of the SSME fuel and oxidizer valves are accomplished with two combined checks. One check verifies the fuel system by installing a throat plug in the engine bell and pressurizing the LH2 feed system from a ground supplied GHe source connected to the main LH2 inlet. Flow is measured with a flow meter at the throat plug. This checks the high & low pressure turbopump liftoff seals within the fuel turbopumps and the main fuel valve seals. A second combined check verifies the oxidizer feed system and is performed in the same manner with a GN2 source connected to the main LOX inlet.

### 3.5 External Leak Checks

External leak checks are those checks which measure leakage from joint seals, line fittings or welds to the outside atmosphere. They determine the integrity of the engine fuel and oxidizer plumbing. The techniques employed to detect leaks are basically the same for both the RL10 and the SSME using leak detection fluid (bubble soap), mass spectrometers and gas analyzers.

For the external leak checks on the RL10 fuel system, a GHe supply is connected to a tee fitting in the fuel pump inlet pressure sense line. A pressure gage is connected to the gearbox purge fitting. Leak check fluid is then applied to the various engine parts. The GHe pneumatic control system is checked by connecting the GHe supply line to the engine GHe supply fitting, the prestart and start solenoids are energized and leak detection fluid is applied to various valves. A pressure decay test of the GHe control system is also performed with the prestart and start solenoids both energized and de-energized.

The SSME Hot Gas Manifold (HGM) leak check is a combined check which verifies the integrity of the hot gas manifold and the preburners. During this check all Orbiter aft access/vent doors except one are closed, and the main propulsion system is pressurized with He through the throat plug. The Orbiter aft section is purged and the GHe contained in the purge air is measured. Leak check fluid and a pneumatic flow tester are used to check for nozzle, valve flanges and line leaks.

## 4.0 Lunar Excursion Vehicle Functional Tests

Resources for LEV/MEV functional test will be extremely limited. Crew size for example will be limited to four crew members under the SEI 90-Day Study architectures, and six crew members under the plan proposed in the Syntheses Group Report. Support equipment will also be limited. The LEV/MEV Servicer will be available on a planetary surface; however, external support equipment will not be available in low lunar orbit for preflight checks prior to descent burn.

Performing engine functional tests using techniques currently employed for the RL10 will be totally impractical. The LEV/MEV engines will require a high degree of self test capability. The following paragraphs provide some suggested methods for implementing these self test features.

## 4.1 Torque Checks

If considered essential for the LEV/MEV engine, a torque check of the turbine could be accomplished by driving the turbine with a small built-in electrical motor and a computer calculation of the breakaway and running torque based on motor current and turbine RPM. However, shaft travel measurements, such as those performed on the SSME, may be more difficult, or impossible, to accomplish in space or on a planetary surface.

## 4.2 Electrical Checks

The electrical system insulation resistance checks and the electrical bonding checks performed on the LEV/MEV engines should be retained as post manufacturing checks, and should not be repeated as functional tests.

Ignition systems checks could be accomplished on a planetary surface, or in space, as an automated checkout under computer control, using built-in instrumentation, similar to the SSME.

Since, the purpose of RL10 ignition system deflection check is to verify proper pressurization of the igniter box, this check could be accomplished by adding a pressure sensor to the box. There is no corresponding check performed on the SSME, which indicates that the igniter circuits are not subject to arcing. A recommended approach for the LEV/MEV is to use an advanced igniter system similar to the SSME.

## 4.3 Valve Actuation Checks

Actuation checks of all valves should be accomplished as part of a timed sequence test. The valves on the RL10 engine could be cycled dry at ambient temperatures under computer control by installing shutoff valves at the outlets of the fuel and oxidizer tanks and installing position indicators on the valves. Valve positions and timing would be verified by the computer similar to the SSME.

## 4.4 Internal Leak Checks

Leak tests of this type (checking flow rates through individual components) in the same manner as performed for the RL10 would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in test equipment and sensors and performed under computer control similar to the approach used for the SSME is the recommended approach.

## 4.5 External Leak Checks

External leaks involving liquid rocket propellants on earth are a particular concern because of the hazards presented by oxygen in the atmosphere. In the vacuum environment of a planetary surface and LLO/LMO, minor hydrogen and oxygen leaks should not present a serious problem as long as the leaks do not degrade engine performance beyond acceptable limits. The best way to measure performance and check functionality is to fire the engine. On the Orbiter for example the SSMEs are started and performance verified prior to igniting the solid rocket boosters (SRBs). If any of the SSMEs fail to start or the performance is marginal the SRBs are not ignited, the SSMEs are shut down and the launch is aborted.

This would be the recommended approach for launches from a planetary surface provided the LEV/MEV engines can be started in a throttled down condition (e. g., 20% of rated thrust) such that there is no tendency to lift-off. However, firing the LEV/MEV engines to measure performance, prior to descent from orbit may not be practical, because any thrust produced by the engines would affect the vehicle's orbit.[1]

## 4.6 Combined Leak Checks

If engine firing prior to launch to LLO/LMO or descent from LLO/LMO is found to be impractical, some type of combined pressure decay check may provide a degree of confidence that internal/external leaks are not excessive. However, performing leak checks by installing a plug in the throat of the engine and the use of flow meters and leak check fluid is not practical in space. In addition, the RL10 is not designed to hold pressure and pressure would migrate between the fuel and oxidizer sections in about 20 minutes. In order to provide a pressure decay check, capability the RL10 would require the following design changes:

- Redesign of the inlet valves to provide double seals
- Relocation of the main fuel shutoff valve and the oxidizer flow control valve as close as possible to the injector
- Redesign of the main fuel shutoff valve and the oxidizer flow control valve to provide better seals

---

1 Until an analysis is performed to determine whether the impact could be nullified in some manner, this would not be considered a viable option for the predescent engine checkout.

- Redesign of the oxidizer flow control valve to restrict all cooldown propellant flow through the prestart oxidizer flow section of the valve
- Redesign of the pneumatic control circuits to provide three way valves which would port GHe to close the prestart oxidizer flow section of the oxidizer flow control valve, plus the interstage and discharge cooldown valves, and their associated vent ports, during the pressure decay test
- Redesign of the pneumatic control circuits would include valves to port GHe to pressurize the fuel and oxidizer lines through the injection points
- Possible redesign of the turbopump drive gear assembly to improve isolation seals between the fuel and oxidizer sections
- Redesign of the fuel and oxidizer lines to include pressure and temperature sensors at various locations to provide input to the LEV/MEV computer
- Additional GHe supply bottle(s) and associated plumbing would have to be required in order to pressurize the fuel and oxidizer systems

A trade study would be required to determine if pressure decay tests would provide a practical solution to determining engine integrity with respect to internal/external leaks, and then evaluate the achievable benefits when measured against the weight penalties associated with the redesign. If the trade study results indicate that pressure decay tests provide a practical solution, then the design changes described above would have to be compatible with the RL10 redesign necessary to meet the requirements associated with the LEV/MEV (i. e., man-rating, reusability, incorporation of BIT/BITE, high reliability, etc.). Design improvements such as welded joints, better valve seals, embedded sensors, etc. may eliminate the need to consider pressure decay tests.

## 4.7 Preflight Functional Test Sequence

Assuming that the LEV/MEV advanced design RL10 engines include a computer controlled BIT/BITE capability, and that a pressure decay test can be used as a combined internal/external leak check, a hypothetical test sequence can be developed as described below:

1. Avionics self test, including engine sensor calibration and check out of igniters, would be the first test in the sequence of engine functional checks. These self tests would be

initiated and monitored by the LEV/MEV main computer in a manner similar to the techniques employed by the Orbiter.

2. A torque check of the turbine would be the next step and would be accomplished by driving the turbine with a small built-in electrical motor and a computer calculation of the breakaway and running torque based on motor current and turbine RPM.

3. After the turbine operation is verified, the engine valves would be dry cycled (i. e., propellant tank outlet valves closed) and their operation verified with the computer by detecting valve position from position sensors and measuring the response time.

4. A combined internal/external leak check of the fuel system would then be performed by pressuizing the system from the fuel pump inlet shutoff valve to the main fuel shutoff valve (see figure 2.1-1) and checked for excessive pressure decay.

5. The oxidizer system would then be pressurized from the oxidizer pump inlet shutoff valve to the oxidizer flow control valve and checked for excessive pressure decay.

6. Following the pressure decay checks the propellant tank outlet valves would be opened to allow fuel and oxidizer to flow down to the fuel and oxidizer pump inlet shutoff valves. Pressure and temperature sensors at various points in the systems would be used to verify proper fuel and oxidizer flow.

7. A prestart cooldown would then be initiated by allowing fuel to flow through the fuel pump and vented overboard through vents in the fuel cooldown valves to cool the pump to operating temperature. A small amount of fuel would be allowed to flow through the main fuel shut-off valve and out of the thrust chamber. The oxidizer pump would be cooled by flowing oxygen through the oxidizer pump and through the prestart section of the oxidizer flow control valve. Pressure and temperature sensors at various points would be used to verify proper fuel and oxidizer flow.

8. The final step in the engine functional check would be a low thrust firing, prior to lift-off from the planetary surface, where engine temperatures and pressures would be measured at various points with embedded sensor during an actual low thrust start and short burn period. The computer would compare these data with known temperature profiles to verify proper engine performance. Figure 4.7-1 is an illustration of a temperature and pressure profile for the RL10 during normal operating conditions. Similar profiles could be developed for various operating conditions to provide continuous performance monitoring by the computer.

   If engine performance is not within established boundaries the vehicle launch would be aborted. If the engine performance was within proper boundaries the engine would throttled up to launch thrust levels.[2]

## 5.0 Conclusions and Summary

The LEV/MEV concepts developed during the Space Exploration Initiative (SEI) transportation studies used multiple cryogenic propellant (LOX/LH2) engines, with a combined thrust level in the range of 60,000 to 80,000 pounds. Advanced models of the RL10 were the engines of choice. One of the major design improvements required for on-orbit or planetary preflight functional verifications would be the incorporation of embedded sensors and computer controlled test programs to provide a BIT/BITE capability.

Recommended checks that should be considered for the preflight functional test are:

1. Electrical system tests, including ignition system verification

2. Turbine torque checks

3. Valve actuation checks

4. Combined internal/external fuel system leak checks (pressure decay checks)

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2 If practical, this prelaunch firing test could be substituted for the pressure decay tests described in steps 4 and 5.

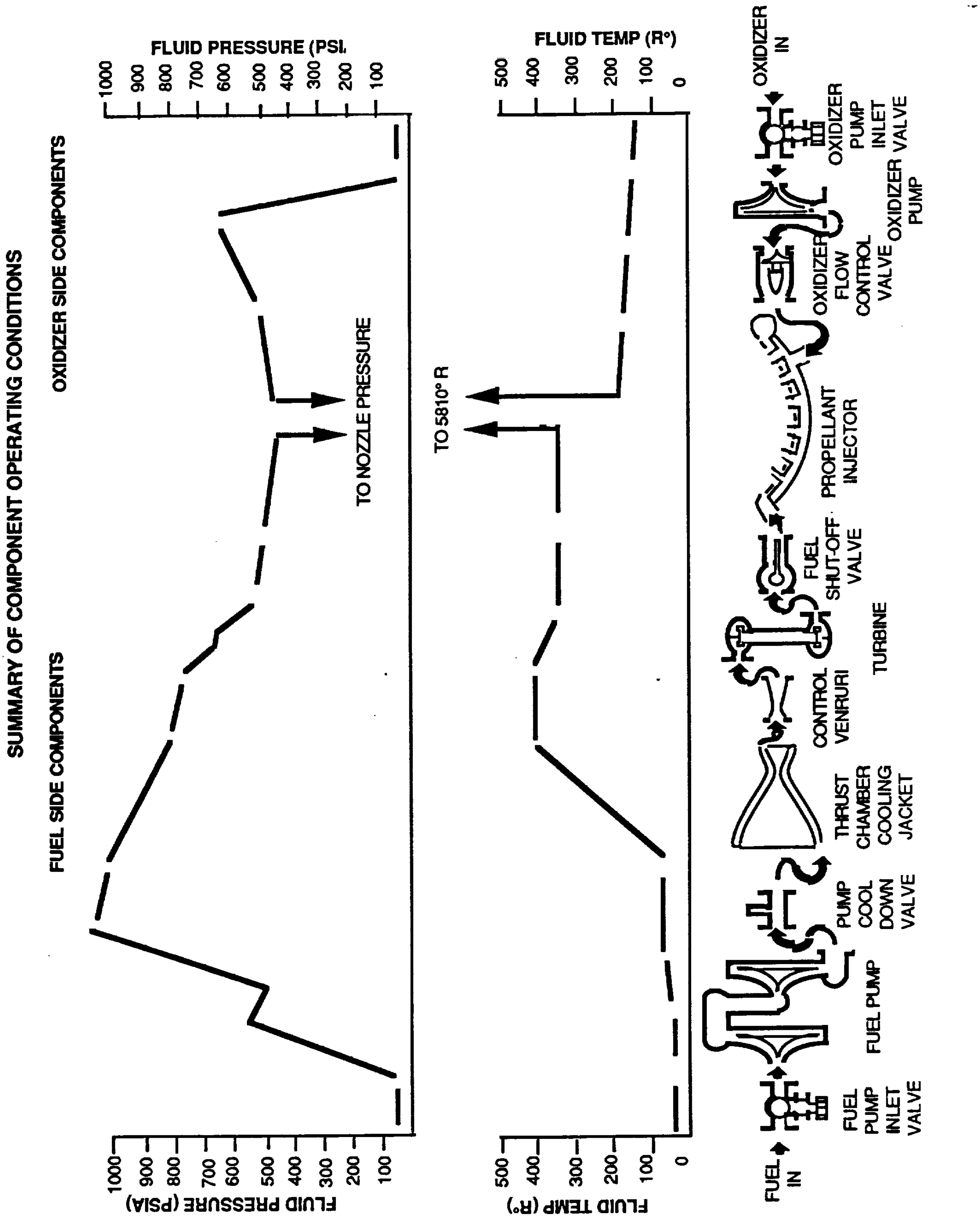


Figure 4.7-1: RL10 Temperature and Pressure Profile

5. Combined internal/external oxidizer system leak checks (pressure decay checks)

6. Flow check of fuel and oxidizer from the vehicle tanks to the pump inlet shutoff valves

7. Cooldown fuel and oxidizer flow check

8. Low thrust engine performance check[2]

## Appendix A
## List of Acronyms

| | |
|---|---|
| BIT/BITE | Built-in-test/Built-in-test-equipment |
| CCV | Chamber Coolant Valve |
| CTP | Centaur Test Procedure |
| FPOV | Fuel Preburner Oxidizer Valve |
| GHe | Gaseous Helium |
| GN2 | Gaseous Nitrogen |
| HGM | Hot Gas Manifold |
| HPFTP | High Pressure Fuel Turbopump |
| HPOTP | High Pressure Oxidizer Turbopump |
| LEV | Lunar Excursion Vehicle |
| LH2 | Liquid Hydrogen |
| LLO | Low Lunar Orbit |
| LMO | Low Martian Orbit |
| LOX | Liquid Oxygen |
| LPFTP | Low Pressure Fuel Turbopump |
| LPOTP | Low Pressure Oxidizer Turbopump |
| LPS | Launch Processing System |
| MEV | Mars Excursion Vehicle |
| MFV | Main Fuel Valve |
| MOV | Main Oxidizer Valve |
| NASA | National Aeronautics and Space Administration |
| OMI | Operations and Maintenance Instruction |
| OPF | Orbiter Processing Facility |
| OPOV | Oxidizer Preburner Oxidizer Valve |
| SEI | Space Exploration Initiative |
| SRB | Solid Rocket Booster |
| SSME | Space Shuttle Main Engine |
| VAB | Vehicle Assembly Building |

Attachment 1

# White Paper on Comparison of the Functional Testing of the RL10 Liquid Rocket Engine and the Space Shuttle Main Engine (SSME)

11 September 1991

prepared for

Office of Advanced Systems and Technology
NASA Kennedy Space Center

prepared by

McDonnell Douglas Space Systems Company
Kennedy Space Center

NASA Contract Number: NAS10-11567

# RL10/SSME Functional Tests (Explanation of Field Entries)

**RL10 Para No.*** **Title (RL10)**

1. Reference Para No. — Title of RL10 functional test.

**Description (RL10)**

Brief discription of how the test is conducted on the RL10.

**Used During Centaur Preflight**

Functional testing of the RL10 engines is perfromed at the factory prior to shipment and storage, again upon removal from storage and in some cases during preflight just prior to launch. Repeating the test during preflight would indicate that the particular function is considered highly critical.

**SSME Para No.**** **Title (SSME)**

Reference OMI & Para No. — Title of the OMI, or the specfic test, which is similar to the corresponding RL10 test.

**Description (SSME)**

Brief description of how the test is performed on the Orbiter SSME.

**Used During Shuttle Preflight**

The Orbiter SSMEs are removed from the Orbiter after each flight and functional testing is generally accomplished at the SSME Engine Shop. However, certain test can be performed after installation in the Orbiter at the VAB and/or at the pad.

**LEV Pre/Post Flt**

This field provides an indication of the applicabiity of the RL10/SSME function tests to the LEV preflight testing, along with sugestions for implementation.

**List of Acronyms**

BIT/BITE - Built-in-test/Built-in-test-equipment
CCV - Chamber Coolant Valve
CTP - Centaur Test Procedure
FPOV - Fuel Preburner Oxidizer Valve
GHe - Gaseous Helium
GN2 - Gaseous Nitrogen
HGM - Hot Gas Manifold
HPFTP - High Pressure Fuel Turbopump
HPOTP - High Pressure Oxidizer Turbopump
LEV - Lunar Excursion Vehicle
LH2 - Liquid Hydrogen
LLO - Low Lunar Orbit
LMO - Low Martian Orbit
LOX - Liquid Oxygen
LPFTP - Low Pressure Fuel Turbopump
LPOTP - Low Pressure Oxidizer Turbopump
LPS - Launch Processing System
MEV - Mars Excursion Vehicle
MFV - Main Fuel Valve
MOV - Main Oxidizer Valve
NASA - National Aeronautics and Space Administration
OMI - Operations and Maintenance Instruction
OPF - Orbiter Processing Facility
OPOV - Oxidizer Preburner Oxidizer Valve
SEI - Space Exploration Initiative
SRB - Solid Rocket Booster
SSME - Space Shuttle Main Engine
VAB - Vehicle Assemble Building

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSMF OMI/Paragraph
*** CT[illegible] OP-3131 & CTP-PROP-3133 are General Dynamics [illegible]'aur Test Procedures

# RL10/SSME F ional Tests

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.01 | RL10 Functional Tests - Equipment | N/A | |

**Description (RL10)**

Test paragraph lists and describes the test equipment required to perform the functional tests.

**Description (SSME)**

**Used During Centaur Preflight**

Some of this equipment is used for those functional tests that are repeated during preflight testing.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

LEV Servicer will be available on the lunar surface. However, external support equipment will not be available in LLO for preflight checks prior to descent burn.

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.02 | Turbopump - Torque Check | V1011.03<br>02-000 - 16-000 | HPOTP, HPFTP, LPOTP & LPFTP Torque & Shaft<br>Travel Check (Post Engine Installation) & (Post Flight) |

**Description (RL10)**

This is a manual check of the breakaway and running torque of the turbopump and gearing. The turbopump gears are rotated clockwise and counterclockwise. These measurements are made at the accessory drive spline and a cover plate must be removed to gain access.

**Description (SSME)**

This is a manual check of the breakaway and running torque of the high and low pressure oxidizer and fuel turbopumps and gearing. The turbopumps and gears are rotated clockwise. Measurements are made at the drive shafts. Cover plates must be removed to gain access to the shafts.

Shaft travel is also measured and compared to previous measurements to ensure travel is within limits.

**Used During Centaur Preflight**

P&W recommends that this test be performed during preflight only if the hydraulic power pack is removed for maintenance. However, CTP-PROP-3133*** calls for the hydraulic power pack to be removed and torque checks performed on the turbopump and the hydraulic power pack.

**Used During Shuttle Preflight**

Performed after initial firing of a new vehicle (Flight Readiness FiringTest) at the pad and as a post flight check at the SSME Engine Shop thereafter.

**LEV Pre/Post Flt**

If considered essential this could be accomplished with a small built-in electrical motor and built-in instrumentation. However, shaft travel measurements maybe more difficult, or impossible, to accomplish in space or on the lunar surface.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

| **RL10 Para No.*** | **Title (RL10)** | **SSME Para No.**** | **Title (SSME)** |
|---|---|---|---|
| 6.03 | Oxidizer Flow Control Valve (Propellant Utilization) - Torque Check | N/A | |

**Description (RL10)**

This is a manual check of the torque required to move the oxidizer flow control valve. The measurements are made at the valve spline and a cover plate must be removed to gain access.

**Description (SSME)**

**Used During Centaur Preflight**

P&W recommends that this test be performed during preflight only if the hydraulic power pack is removed for maintenance. However, CTP-PROP-3133*** calls for the hydraulic power pack to be removed and torque checks performed on the turbopump and the hydraulic power pack.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

If considered essential this could be accomplished with a small built-in electrical motor and built-in instrumentation.

| **RL10 Para No.*** | **Title (RL10)** | **SSME Para No.**** | **Title (SSME)** |
|---|---|---|---|
| 6.04 | Electrical System - Check | N/A | |

**Description (RL10)**

This is a series of resistance measurements with a megohmmeter between connector pins, within a connector, and from connector pins in a connector to the connector shell. Also, it includes continuity checks of solenoids, sensors and transducers.

**Description (SSME)**

**Used During Centaur Preflight**

No.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

These are really post manufacturing checks, and should not be repeated.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** C ROP-3131 & CTP-PROP-3133 are General Dynamic ntaur Test Procedures

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.05 | Electrical Bonding - Test | N/A | |

**Description (RL10)**

This is a check of the resistance between the connector shells and the mounting brackets.

**Used During Centaur Preflight**

No.

**LEV Pre/Post Flt**

These are really post manufacturing checks, and should not be repeated.

**Description (SSME)**

**Used During Shuttle Preflight**

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.06 | Ignition System - Electrical Check (A-3-3A) | V1011.04<br>03-000 - 03-029 | Sensor/Igniter/Redundancy Checkout |

**Description (RL10)**

This check includes a check of the operation of the ignition system using ground power and a voltmeter to measure the output of a voltage at an indicator/monitor circuit, a visual observation of the spark for at least 10 seconds, and resistance checks.

**Used During Centaur Preflight**

Yes.

**Description (SSME)**

This is an automated calabration of the sensors and a checkout of igniters and redundancy circuits performed prior to orbiter rollout from the OPF. Although the actual test is automated, test equipment set-up requires approximately eight hours to complete.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

This could be accomplished on the luanr surface as an automated checkout under computer control, similar to the SSME, if the LEV can be designed with built-in instrumentation.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

**RL10 Para No.*** **Title (RL10)**
6.07 Ignition System - Electrical Check (A-4)

**Description (RL10)**

Same as RL10-A-3A above.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**
V1011.04
03-000 - 03-029

**Description (SSME)**

Same as above

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

This could be accomplished on the lunar surface as an automated checkout under computer control, similar to the SSME, if the LEV can be designed with built-in instrumentation.

**RL10 Para No.*** **Title (RL10)**
6.08 Ignition System - Deflection Measurement Check

**Description (RL10)**

These checks are performed prior to engine installation on the vehicle, immediately prior to shipment of the vehicle to the launch site and every 30 days at the launch site. The last check shall not be more than one day prior to launch. This is a measure of the deflection of the ignition system exciter box.

**Used During Centaur Preflight**

Yes. The igniter system for the RL10 is an old vacuum tube design and the box containing the circuitry must be pressurized to prevent arcing at high altitudes. This electrical test is actually a check of the pressurization of the ignition exciter box by measuring its deflection.

**SSME Para No.**** **Title (SSME)**
N/A

**Description (SSME)**

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Since, the purpose of RL10 ignition system deflection check is to verify proper pressurization of the igniter box, this check could be accomplished by adding a pressure sensor to the box. There is no corresponding check performed on the SSME, which indicates that the igniter circuits are not subject to arcing. A recommended approach for the LEV/MEV is to use an advanced igniter system similar to the SSME.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSMF OMI/Paragraph
*** CT OP-3131 & CTP-PROP-3133 are General Dynamics aur Test Procedures

# RL10/SSME Fu onal Tests

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.09 | Prestart and Start Solenoid Valves - Actuation Check | V1011.06<br>05-000 - 027 | Acuator Checkout |

**Description (RL10)**

This is a check of the actuation of the prestart and start solenoid valves using ground power and a ground helium supply. Energizing the prestart and start solenoids will actuate the inlet valves. Actuation is verified audibly and by feeling the valve housing.

**Description (SSME)**

The SSME valves are hydraulicaly operated. Actuation of the SSME valves ( MFV, MOV, FPOV, OPOV, CCV) is verified by cycling the valves under computer contol.

**Used During Centaur Preflight**

Yes.

**Used During Shuttle Preflight**

Performed in the OPF as part of the Orbiter prelaunch processing.

**LEV Pre/Post Flt**

Actuation checks of all valves should be accomplished as part of a timed sequence test. The valves could be cycled dry under computer control by installing shutoff valves at the outlets of the fuel and oxidizer tanks and installing position indicators on the valves. Valve positions and timing would be verified by the computer.

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.10 | Fuel and Oxidizer Inlet Shutoff Valve - Actuation Check | V1011.06<br>05-000 - 027 | Acuator Checkout |

**Description (RL10)**

This is a check of the actuation of the fuel and oxdizer inlet shutoff valves by actuating the two prestart and start solenoid valves using ground power and a ground helium supply. Energizing the prestart and start solenoids actuates the inlet valves. Actuation is verified visually and the fuel and oxidizer pump inlets are inspected with black light for hydrocarbon contamination.

**Description (SSME)**

The SSME valves are hydraulicaly operated. Actuation of the SSME valves ( MFV, MOV, FPOV, OPOV, CCV) is verified by cycling the valves under computer contol.

**Used During Centaur Preflight**

Yes.

**Used During Shuttle Preflight**

Performed in the OPF as part of the Orbiter prelaunch processing.

**LEV Pre/Post Flt**

Actuation checks of all valves should be accomplished as part of a timed sequence test. The valves could be cycled dry under computer control by installing shutoff valves at the outlets of the fuel and oxidizer tanks and installing position indicators on the valves. Valve positions and timing would be verified by the computer.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.

** SSME OMI/Paragraph

*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

**RL10 Para No.*** **Title (RL10)**

6.11 Fuel Pump Cooldown Valve - Actuation Check

**Description (RL10)**

This is a visual check of the actuation of the fuel pump cooldown valve and can be accomplished when the actuation of the oxidizer prestart and start valves are verified by energizing the prestart and start valves.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**

N/A

**Description (SSME)**

The SSME uses recirculation system which allows liquid hydrogen to flow from the hydrogen tank, through the fuel system and back to the tank as pressurized gas, for chilldown. The oxidizer system is chilled down by allowing the LOX to flow through the system and vent to the atmosphere.

**Used During Shuttle Preflight**

Recirculation system is active whenever propellant tanks are filled.

**LEV Pre/Post Flt**

It is recommended that the LEV be designed use the actual liquid propellants, similar to the Orbiter system, for chilldown rather than cold helium, so that special cooldown valves and associated tests would not be required.

**RL10 Para No.*** **Title (RL10)**

6.12 Main Fuel Shutoff Valve - Actuation Check

**Description (RL10)**

This is a check of the actuation of the main fuel shutoff valve and can be accomplished when the actuation of the oxidizer prestart and start valves are verified by energizing the prestart and start valves. Actuation is verified by feeling the valve housing.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**

V1011.06 Acuator Checkout
05-000 - 027

**Description (SSME)**

The SSME valves are hydraulicaly operated. Actuation of the SSME valves ( MFV, MOV, FPOV, OPOV, CCV) is verified by cycling the valves under computer contol.

**Used During Shuttle Preflight**

Performed in the OPF as part of the Orbiter prelaunch processing.

**LEV Pre/Post Flt**

Actuation checks of all valves should be accomplished as part of a timed sequence test. The valves could be cycled dry under computer control by installing shutoff valves at the outlets of the fuel and oxidizer tanks and installing position indicators on the valves. Valve positions and timing would be verified by the computer.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CT )P-3131 & CTP-PROP-3133 are General Dynamics ıur Test Procedures

# RL10/SSME Fu ,onal Tests

**RL10 Para No.*** **Title (RL10)**

6.13 Oxidizer Flow Control Bypass Valve - Actuation Check

**Description (RL10)**

This is a check of the actuation of the oxidizer flow control bypass valve and can be accomplished when the actuation of the oxidizer prestart and start valves are verified. Actuation is verified by feeling the valve housing.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**

V1011.06 Acuator Checkout
05-000 - 027

**Description (SSME)**

The SSME valves are hydraulicaly operated. Actuation of the SSME valves ( MFV, MOV, FPOV, OPOV, CCV) is verified by cycling the valves under computer contol.

**Used During Shuttle Preflight**

Performed in the OPF as part of the Orbiter prelaunch processing.

**LEV Pre/Post Flt**

Actuation checks of all valves should be accomplished as part of a timed sequence test. The valves could be cycled dry under computer control by installing shutoff valves at the outlets of the fuel and oxidizer tanks and installing position indicators on the valves. Valve positions and timing would be verified by the computer.

**RL10 Para No.*** **Title (RL10)**

6.14 Oxidizer Flow Control and Purge Relief Valve - Pressure and Leak Check

**Description (RL10)**

Pressure and leak test of this valve is accomplished with ground GN2, a pressure gage and a flow meter. A protective cover and/or a dessicant has to be removed to connect the GN2 line and flow meter. Flow rate is measured though the valve at high (4.0 psig) and low (0.5 psig) pressures.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**

V1011.05 HGM/LOX/LH2 System Leak Checks (Combined Leak & Functional Checks)
05-000 - 13-026

**Description (SSME)**

A throat plug is installed in the engine bell and the LH2 /LOX feed systems are pressurized from a source connected to the main LH2/LOX inlets, flow is measured with a flowmeter at the throat. This checks the high & low turbopump liftoff seals and the main LH2/LOX valve seals. For the HGM leak checks, all Orbiter aft acess/vent doors except one are closed, the main propulsion system is pressurized with He through the throat plug. The Orbiter is purged and the He in the purge air is measured. Leak check fluid & pneumatic flowtester is used to check for nozzle, valve & line leaks.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

| RL10 Para No.* | Title (RL10) | SSME Para No.** Title (SSME) |
|---|---|---|
| 6.15 | Engine Systems - Preparation for Pressure and Leak Check | N/A |

**Description (RL10)**

This is a set of procedures for preparing the engine for pressure and leak tests such as removing shipping closures, dessicants, installing pressure caps, and the pressure check plug in the throat of the thrust chamber.

**Description (SSME)**

**Used During Centaur Preflight**

Yes.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

These procedures and preparations are required for checks that are performed manually and are not applicable to operations conducted in space or on planetary surfaces.

| RL10 Para No.* | Title (RL10) | SSME Para No.** Title (SSME) |
|---|---|---|
| 6.16 | Oxidizer Inlet Shutoff Valve Pressure and leak Check (Leakage Past the Ball) | N/A |

**Description (RL10)**

Pressure and leak test of this valve is accomplished with ground GHe, a pressure check plug in the throat of the thrust chamber and a flow meter. The GHe line is connected a fitting on the inlet shutoff shipping cover. Flow rate is measured by the flow meter connected to a throat plug fitting.

**Description (SSME)**

Oxidizer inlet shutoff valve is part of the Orbiter and not part of the SSME.

**Used During Centaur Preflight**

No.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.

** SSME OMI/Paragraph

*** C[illegible] ROP-3131 & CTP-PROP-3133 are General Dynamics [illegible]taur Test Procedures

# RL10/SSME Fu onal Tests

**RL10 Para No.*** **Title (RL10)**
6.17 Fuel Inlet Shutoff Valve - Pressure and leak Check (Leakage Past the Ball)

**Description (RL10)**

Same as paragraph 6.16 above

**Used During Centaur Preflight**

No.

**SSME Para No.**** **Title (SSME)**
N/A

**Description (SSME)**

Fuel inlet shutoff valve is part of the Orbiter and not part of the SSME.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

**RL10 Para No.*** **Title (RL10)**
6.18 Main Fuel Shutoff Valve - Pressure and leak Check (Gate Leakage Check)

**Description (RL10)**

Same as above, except allowable flow is much higher, and both minimum and maximum values are measured. Pressure is also measured during this check by installing a gage at the gearbox purge fitting.

**Used During Centaur Preflight**

No.

**SSME Para No.**** **Title (SSME)**
V1011.05
05-000 - 13-026 HGM/LOX/LH2 System Leak Checks (Combined Leak & Functional Checks)

**Description (SSME)**

A throat plug is installed in the engine bell and the LH2 /LOX feed systems are pressurized from a source connected to the main LH2/LOX inlets, flow is measured with a flowmeter at the throat. This checks the high & low turbopump liftoff seals and the main LH2/LOX valve seals. For the HGM leak checks, all Orbiter aft acess/vent doors except one are closed, the main propulsion system is pressurized with He through the throat plug. The Orbiter is purged and the He in the purge air is measured. Leak check fluid & pneumatic flowtester is used to check for nozzle, valve & line leaks.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

**RL10 Para No.*** **Title (RL10)**
6.19 Prelaunch Cooldown Check Valve - Pressure and Leak Check

**Description (RL10)**

Pressure and leak test of this valve is accomplished with ground GHe, a pressure check plug in the throat of the thrust chamber and a flow meter. The GHe line is connected a fitting on the fuel pump interstage cooldown valve vent. Flow rate is measured at in the GHe inlet of the cooldown check valve.

**Used During Centaur Preflight**

No.

**SSME Para No.**** **Title (SSME)**
N/A

**Description (SSME)**

The SSME uses a recirulation system which allows liquid hydrigen to flow from the hydrogen tank, through the fuel system and back to the tank as pressurized gas, for chilldown. The oxidizer system is chilled down by allowing the LOX to flow through the system and vent to the atmosphere.

**Used During Shuttle Preflight**

Recirculation system is active whenever propellant tanks are filled.

**LEV Pre/Post Flt**

It is recommended that the LEV be designed to use the actual liquid propellants, similar to the Orbiter system, for chilldown rather than liquid helium, so that special cooldown valves and associated tests would not be required.

**RL10 Para No.*** **Title (RL10)**
6.20 Prelaunch Cooldown Check Valve Inlet Adapter - Torque Check

**Description (RL10)**

This a check of the torque on an adapter between the valve body and the LHe inlet line.

**Used During Centaur Preflight**

P&W does not require this test to be performed as part of the preflight, however, CTP-PROP-3131*** specifies that it be performed as part of the leak and functional test.

**SSME Para No.**** **Title (SSME)**
N/A

**Description (SSME)**

The SSME uses a recirulation system which allows liquid hydrigen to flow from the hydrogen tank, through the fuel system and back to the tank as pressurized gas, for chilldown. The oxidizer system is chilled down by allowing the LOX to flow through the system and vent to the atmosphere.

**Used During Shuttle Preflight**

Recirculation system is active whenever propellant tanks are filled.

**LEV Pre/Post Flt**

It is recommended that the LEV be designed to use the actual liquid propellants, similar to the Orbiter system, for chilldown rather than liquid helium, so that special cooldown valves and associated tests would not be required.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** C[illegible]OP-3131 & CTP-PROP-3133 are General Dynamics [illegible]taur Test Procedures

**RL10 Para No.*** **Title (RL10)**

6.21 Main Fuel Shutoff Valve - Pressure and Leak Check (Lip Seal Leakage)

**Description (RL10)**

Pressure and leak test of this valve is accomplished with ground GHe, a pressure check plug in the throat of the thrust chamber, a pressure gage and a flow meter. The GHe line is connected a fitting on the supply fitting of the cooldown valve pressure check plates. The pressure gage is connected to the gearbox purge connector. Flow rate is measured by the flow meter connected to the main fuel shutoff valve vent tube.

**Used During Centaur Preflight**

No.

**SSME Para No.**** **Title (SSME)**

V1011.05 HGM/LOX/LH2 System Leak Checks (Combined Leak & Functional Checks)
05-000 - 13-026

**Description (SSME)**

A throat plug is installed in the engine bell and the LH2 /LOX feed systems are pressurized from a source connected to the main LH2/LOX inlets, flow is measured with a flowmeter at the throat. This checks the high & low turbopump liftoff seals and the main LH2/LOX valve seals. For the HGM leak checks, all Orbiter aft acess/vent doors except one are closed, the main propulsion system is pressurized with He through the throat plug. The Orbiter is purged and the He in the purge air is measured. Leak check fluid & pneumatic flowtester is used to check for nozzle, valve & line leaks.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

**RL10 Para No.*** **Title (RL10)**

6.22 Oxidizer Flow Control Bypass Valve - Pressure and Leak Check (Lip Seal Leakage)

**Description (RL10)**

Same as paragraph 6.21 above only the the connecting points for the flow meter and the GHe supply are reversed.

**Used During Centaur Preflight**

P&W does not require this test to be performed as part of the preflight, however, CTP-PROP-3131*** specifies that it be performed as part of the leak and functional test.

**SSME Para No.**** **Title (SSME)**

V1011.05
05-000 - 13-026 HGM/LOX/LH2 System Leak Checks (Combined Leak & Functional Checks)

**Description (SSME)**

A throat plug is installed in the engine bell and the LH2 /LOX feed systems are pressurized from a source connected to the main LH2/LOX inlets, flow is measured with a flowmeter at the throat. This checks the high & low turbopump liftoff seals and the main LH2/LOXvalve seals. For the HGM leak checks, all Orbiter aft acess/vent doors except one are closed, the main propulsion system is pressurized with He through the throat plug. The Orbiter is purged and the He in the purge air is measured. Leak check fluid & pneumatic flowtester is used to check for nozzle, valve & line leaks.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CT OP-3131 & CTP-PROP-3133 are General Dynamics aur Test Procedures

**RL10 Para No.*** **Title (RL10)**
6.23 Engine Systems - Pressure and Leak Check

**Description (RL10)**

Pressure and leak checks for fuel and oxidizer systems can be accomplished simultaneously. The pressure check plug remains installed until these checks are completed. A pressure gage is connected to the oxidizer pump inlet tee. The GHe supply line is connected to a tee fitting in the oxidizer pump inlet pressure sense line. Leak check fluid is then applied to the various engine parts.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**
V1011.05 HGM/LOX/LH2 System Leak Checks (Combined Leak &
05-000 - 13-026 Functional Checks)

**Description (SSME)**

A throat plug is installed in the engine bell and the LH2 /LOX feed systems are pressurized from a source connected to the main LH2/LOX inlets, flow is measured with a flowmeter at the throat. This checks the high & low turbopump liftoff seals and the main LH2/LOX valve seals. For the HGM leak checks, all Orbiter aft acess/vent doors except one are closed, the main propulsion system is pressurized with He through the throat plug. The Orbiter is purged and the He in the purge air is measured. Leak check fluid & pneumatic flowtester is used to check for nozzle, valve & line leaks.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

Installing a plug in the throat of the engine and the use of leak check fluid is not practical on the lunar surface. Any type of pressure decay check would require installation of a mechanical shutoff upstream of the injector and valves on the cooldown valve vent lines. The RL10 is not designed to hold pressure and pressure would migrate in about 20 minutes.

**RL10 Para No.*** **Title (RL10)**
6.24 Fuel Inlet Shutoff Valve - Reverse Leakage Check

**Description (RL10)**

The GHe supply is connected to a tee fitting in the fuel pump inlet pressure sense line, a flow meter is connected to the fuel inlet shutoff valve test plate where the reverse flow is measured.

**Used During Centaur Preflight**

No.

**SSME Para No.**** **Title (SSME)**
N/A

**Description (SSME)**

Fuel inlet shutoff valve is part of the Orbiter and not part of the SSME.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* **RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.**
** **SSME OMI/Paragraph**
*** **CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures**

# RL10/SSME Functional Tests

**RL10 Para No.*** **Title (RL10)**
6.25 Oxidizer Inlet Shutoff Valve - Reverse Leakage Check

**Description (RL10)**

The GHe supply is connected to a tee fitting in the oxidizer pump inlet pressure sense line, a flow meter is connected to the oxidizer inlet shutoff valve test plate where the reverse flow is measured.

**Used During Centaur Preflight**

No.

**SSME Para No.**** **Title (SSME)**
N/A

**Description (SSME)**

Oxidizer inlet shutoff valve is part of the Orbiter and not part of the SSME.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

**RL10 Para No.*** **Title (RL10)**
6.26 Fuel System - Pressure and leak Check

**Description (RL10)**

The GHe supply is connected to a tee fitting in the fuel pump inlet pressure sense line, A pressure gage is connected to the gearbox purge fitting. Leak check fluid is then applied to the various engine parts.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**
V1011.05 HGM/LOX/LH2 System Leak Checks (Combined Leak &
05-000 - 13-026 Functional Checks)

**Description (SSME)**

A throat plug is installed in the engine bell and the LH2 /LOX feed systems are pressurized from a source connected to the main LH2/LOX inlets, flow is measured with a flowmeter at the throat. This checks the high & low turbopump liftoff seals and the main LH2/LOX valve seals. For the HGM leak checks, all Orbiter aft acess/vent doors except one are closed, the main propulsion system is pressurized with He through the throat plug. The Orbiter is purged and the He in the purge air is measured. Leak check fluid & pneumatic flowtester is used to check for nozzle, valve & line leaks.

**Used During Shuttle Preflight**

Accomplished in the OPF as part of the Orbiter preflight processing.

**LEV Pre/Post Flt**

The use of leak check fluid on the lunar surface is not practical and some other means of verifying fuel system integrity, such as pressure decay checks, will be required. Leaks would degrade engine performance, but should not be catastrophic in a vacuum environment, particulary if the LEV engine is designed to be vacuum inerted up to the propellant tank shutoff valves, during storage on the lunar surface.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CT P-3131 & CTP-PROP-3133 are General Dynamics ur Test Procedures

# RL10/SSME Fu onal Tests

| **RL10 Para No.*** | **Title (RL10)** | **SSME Para No.**** | **Title (SSME)** |
|---|---|---|---|
| 6.27 | Helium Control System - Pressure and Leak Check | V1011.06<br>02-000 - 02-022<br>04-000 - 04-051 | MPS/SSME/Pneumatic System Leak Checks & Pneumatic(Acuation) Checkout |

**Description (RL10)**

This is a leak test of the GHe control system. The GHe supply line is connected to the engine GHe supply fitting, the prestart and start solenoids are energized and leak detection fluid is applied to various valves.

**Description (SSME)**

Leak checks of the MPS, SSME and Pneumatic joints and lines are made by pressurizing the systems and using leak detection fluid and flow meters.

Actuation of the Pneumatic System is verified by cycling the valves under computer contol. One of the main functions of the pneumatic system is the emergency shutdown of the SSME under emergency conditions Flight Acceleration Safety Cutoff System (FASCOS).

**Used During Centaur Preflight**

Yes.

**Used During Shuttle Preflight**

Performed in the OPF as part of the Prelaunch processing.

**LEV Pre/Post Flt**

Actuation checks of all valves should be accomplished as part of a timed sequence test. The pneumatic system pressure could be monitored with built-in pressure sensors at specific locations during the cycling to determine if leakage is above specified limits.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

Atachment 1

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.28 | Helium Control System - Pressure and Leak Check (Gross Leakage) | V1011.06<br>02-000 - 02-022<br>04-000 - 04-051 | MPS/SSME/Pneumatic System Leak Checks & Pneumatic(Acuation) Checkout |

**Description (RL10)**

This is a pressure decay test of the GHe control system with the prestart and start solenoids both energized and de-energized.

**Used During Centaur Preflight**

No.

**Description (SSME)**

Leak checks of the MPS, SSME and Pneumatic joints and lines are made by pressurizing the systems and using leak detection fluid and flow meters.

Actuation of the Pneumatic System is verified by cycling the valves under computer contol. One of the main functions of the pneumatic system is the emergency shutdown of the SSME under emergency conditions Flight Acceleration Safety Cutoff System (FASCOS).

**Used During Shuttle Preflight**

Performed in the OPF as part of the Prelaunch processing.

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CT( )P-3131 & CTP-PROP-3133 are General Dynamics ( iur Test Procedures

# RL10/SSME Fu ional Tests

**RL10 Para No.*** **Title (RL10)**

6.29 Helium Control System - Gross leakage (Alternate Method Using Launch Vehicle Helium Supply)

**Description (RL10)**

The vehicle GHe supply is used for this check and the leakage flow is measured at the prestart and start solenoid valve vents.

**Used During Centaur Preflight**

Yes.

**SSME Para No.**** **Title (SSME)**

V1011.06 MPS/SSME/Pneumatic System Leak Checks & Pneumatic(Acuation) Checkout
02-000 - 02-022
04-000 - 04-051

**Description (SSME)**

Leak checks of the MPS, SSME and Pneumatic joints and lines are made by pressurizing the systems and using leak detection fluid and flow meters.

Actuation of the Pneumatic System is verified by cycling the valves under computer contol. One of the main functions of the pneumatic system is the emergency shutdown of the SSME under emergency conditions Flight Acceleration Safety Cutoff System (FASCOS).

**Used During Shuttle Preflight**

Performed in the OPF as part of the Prelaunch processing.

**LEV Pre/Post Flt**

Actuation checks of all valves should be accomplished as part of a timed sequence test. The pneumatic system pressure could be monitored with built-in pressure sensors at specific locations during the cycling to determine if leakage is above specified limits.

**RL10 Para No.*** **Title (RL10)**

6.30 Seals - Preparation for Pressure and leak Check

**Description (RL10)**

This is a set of procedures which must be accomplished before performing checks described in paragraphs 6.31 through 6.35. It covers the removal of vent tube assemblies and installing pressure caps on the vents. A flow meter and a GN2 are used in the checks.

**Used During Centaur Preflight**

No

**SSME Para No.**** **Title (SSME)**

N/A

**Description (SSME)**

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

Atachment 1

| **RL10 Para No.*** | **Title (RL10)** | **SSME Para No.**** | **Title (SSME)** |
|---|---|---|---|
| 6.31 | Oxidizer Pump Seal - Pressure and Leak Check | N/A | |

**Description (RL10)**

The GN2 supply is connected to the oxidizer pump inlet tee, and the flow is measured by a flow meter connected to the oxidizer seal vent.

**Description (SSME)**

**Used During Centaur Preflight**

No.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

| **RL10 Para No.*** | **Title (RL10)** | **SSME Para No.**** | **Title (SSME)** |
|---|---|---|---|
| 6.32 | Fuel Bellows Seal - Pressure and Leak Check | N/A | |

**Description (RL10)**

The GN2 supply is connected to the gearbox purge fitting, and the flow is measured by a flow meter connected to the fuel seal vent.

**Description (SSME)**

**Used During Centaur Preflight**

P&W does not require this test to be performed as part of the preflight, however, PROP-3131 specifies that it be performed as part of the leak and functional test.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Leak tests of this type (checking flow rates through individual components) would be impractical in space or on planetary surfaces. Combined checks accomplished with built-in, test equipment and sensors and performed under computer control is the recommended approach.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991,
** SSME OMI/Paragraph
*** CT )P-3131 & CTP-PROP-3133 are General Dynamics ur Test Procedures

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.33 | Accessary Drive Seal - Pressure and Leak Check | N/A | |

| Description (RL10) | Description (SSME) |
|---|---|
| The GN2 supply is connected to the oxidizer pump inlet tee, and the flow is measured by a flow meter connected to the accessory pad vent. | |

| Used During Centaur Preflight | Used During Shuttle Preflight |
|---|---|
| No. | |

**LEV Pre/Post Flt**

Since this check is not performed as part of the Centaur preflight it is not considered necessary for the preflight of the LEV.

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.34 | Oxidizer Pump Ring Seal - Pressure and Leak Check | N/A | |

| Description (RL10) | Description (SSME) |
|---|---|
| The GN2 supply is connected to the oxidizer seal vent, and the flow is measured by a flow meter connected to the propellant vent. | |

| Used During Centaur Preflight | Used During Shuttle Preflight |
|---|---|
| No. | |

**LEV Pre/Post Flt**

Since this check is not performed as part of the Centaur preflight it is not considered necessary for the preflight of the LEV.

* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures

# RL10/SSME Functional Tests

| RL10 Para No.* | Title (RL10) | SSME Para No.** | Title (SSME) |
|---|---|---|---|
| 6.35 | Fuel Ring Seal - Pressure and Leak Check | N/A | |

**Description (RL10)**

The GN2 supply is connected to the ~~fuel~~ leak seal vent, and the flow is measured by a flow meter connected to the propellant seal vent.

**Description (SSME)**

**Used During Centaur Preflight**

No.

**Used During Shuttle Preflight**

**LEV Pre/Post Flt**

Since this check is not performed as part of the Centaur preflight it is not considered necessary for the preflight of the LEV.

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* RL10 Liquid Rocket Engine, Service Manual, 30 March 1991.
** SSME OMI/Paragraph
*** CTP-PROP-3131 & CTP-PROP-3133 are General Dynamics Centaur Test Procedures